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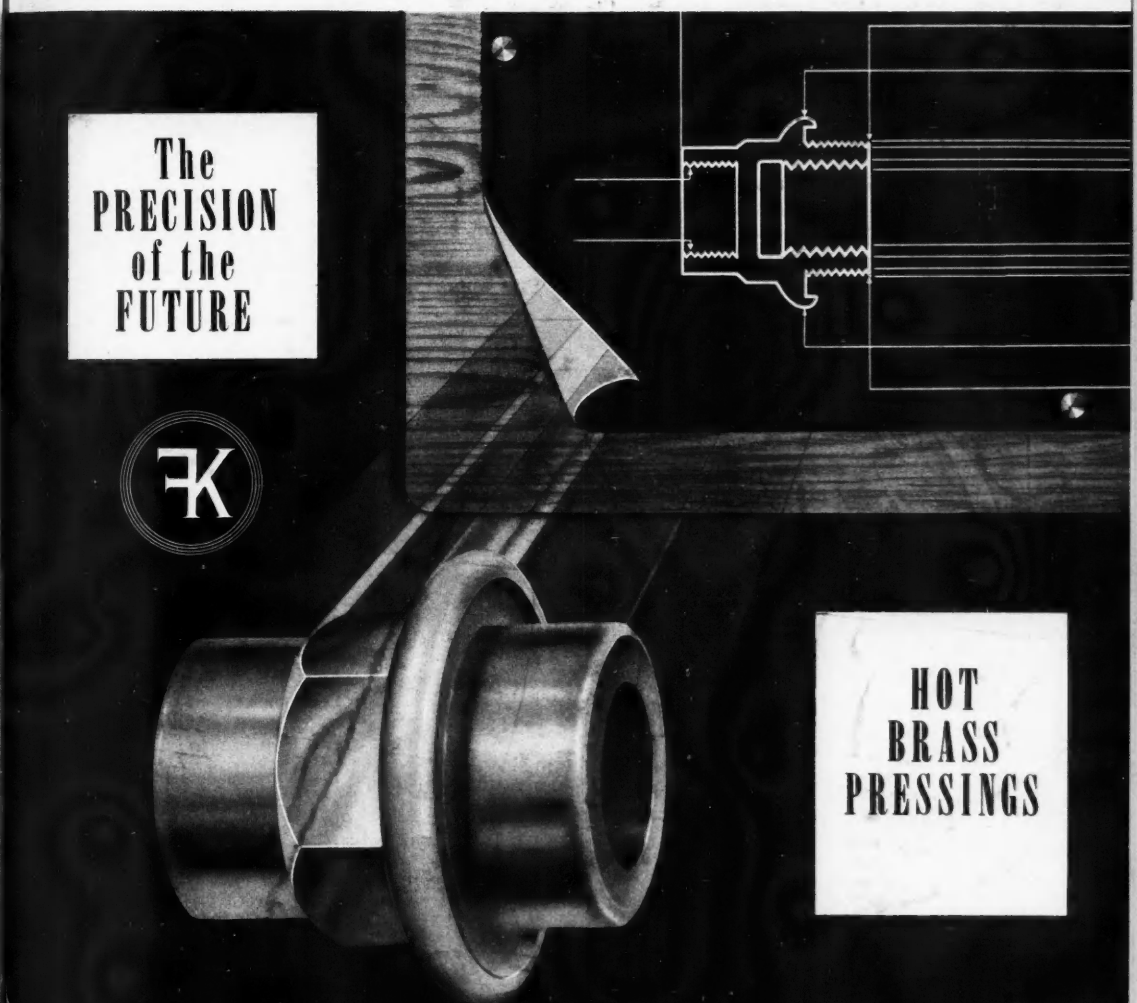
The PRECISION of the FUTURE



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EDITORIAL

AMONG the many interesting displays at the Engineering and Marine Exhibition just concluded, this journal was represented by a Stand designed by Leon Goodman Displays Ltd., who were also responsible for the preparation of two large coloured wall charts depicting the trade distribution, world circulation and readership of "The Engineers' Digest." A special feature of our exhibit was an enlarged replica of this journal, the leaves being continuously turned over in succession by a novel mechanism designed by a member of our editorial staff.

The Exhibition also afforded us an excellent opportunity to deal at first hand with numerous enquiries regarding our new French edition, "Techniques Mondiales," the first issue of which, as mentioned in our August edition, will appear in November next.

The entire Stand was planned to present the fullest possible information on our activities at a glance, and judging from the keen interest expressed by visitors and exhibitors alike, we feel that this policy was well rewarded.

Throughout the Exhibition, as a goodwill gesture to all exhibitors, we placed at their disposal a six-language interpreting service, free of charge.

We sincerely hope that all our friends exhibiting at Olympia met with every success in their efforts to demonstrate the high standard of British engineering products; we ourselves feel certain that they cannot have failed to make an everlasting impression on all visitors.

* * *

On publication of S. E. Noskov's article "Electrolytic Tool Sharpening" in our March, 1949, issue, we promised our readers a further report on this development, to which the attention of British Engineers was first drawn in July, 1947, by our abstract from a Russian paper "Electro-Erosion Cutting of Hard Metal and Steel." In view of the obscurity of various Russian reports, particularly with regard to the physical phenomena involved, we considered it important enough to ask Mr. D. W. Rudorff to clarify the theoretical background of this metal-cutting process and to investigate previously published reports. In the course of this investigation it came to light that the discovery of this phenomenon can be traced back as far as 1898, when G. Bredig succeeded in producing colloidal metals by the direct action of electricity. As readers of the article overleaf will note, his achievement created a considerable stir at the time, but, as so often happens, its possibilities for other applications were not recognized. We hope to be able at some future date to supplement the theoretical discussion published in that issue by an article on the practical application of this process, which would appear to be a most promising production tool of the future.

Our Stand at the Engineering and Marine Exhibition.

* * *

Two leading British scientists, Sir Henry Tizard and Sir Arthur Fleming, addressing the British Association at Newcastle, emphasised the need to bridge the gap between science and industry if the country is to escape economic disaster.

Sir Arthur Fleming, President of the Engineering Section, stated that there is a serious weakness in our national economy, due to the fact that the knowledge available from research is by no means always fully used. "The value of time in making a new idea marketable"—he continued—"seems to be much more acutely realised in America than here, and the reactions in normal times of the American industrialist in this respect are often not far short of those obtaining under war-time stress." The warning of Sir Henry Tizard,

Concluded on page 335

The Electro-Fragmentation Process

By D. W. Rudorff.

The greatly increased use made in recent years of hard metals such as sintered carbides for a variety of purposes, and perhaps even more so the recent developments in the field of highly refractory alloys for high temperature applications in gas turbine construction, have greatly accentuated the need for means enabling the cutting and machining of metals either too hard or too tough to be machined by available methods. It is well-known that the difficulty of finding a satisfactory solution to this problem is greatly aggravated by the fact that thermal fusion processes, including novel processes of torch cutting and friction sawing, can be used only where the unavoidable effects of the cutting heat upon the new surface created by the cut can be tolerated. It goes without saying that this limitation greatly restricts the employment of thermal methods for metal separation—in fact, it restricts these methods to mere cut-off operations.

Where the removal of unwanted material from a hole is to be achieved, such as the extraction of broken taps from holes, the method of disintegrating such material by subjecting it to cyclic heating and chilling, and thus causing quench cracking, has proved its usefulness in recent years. Several types of apparatus generally known as disintegrators or tap extractors have come into use. Finally, attempts have also been made to utilise the well-known electrolytic action of the electric current for the purpose of metal removal.

The fact that by striking a direct current arc between pieces of metal immersed in water, a metal sol can be produced, was discovered in 1898 by G. Bredig[1], who must thus be considered the inventor of the method of preparing colloidal metals by the direct action of electricity. In Bredig's method, a direct current arc is produced under water between wires of the metal concerned by first making contact between the wires and then separating them so as to establish a very short electric arc of a length not exceeding two millimetres. It is stated that the arc could be maintained for several seconds at a time—that is to say, the process was an intermittent one, which was perhaps transformed into a cyclic one by periodical re-establishment of the arc by repetition of contact between the wires. It was observed that in this process very small particles became detached from the cathode and dispersed into the liquid.

Bredig's method created considerable interest at the time and greatly stimulated research in this direction. T. Svedberg[2] experimented with different types of electrical discharges with a view to reducing the decomposition of the liquid by the arc, which in Bredig's method proved particularly unsatisfactory when using organic liquids. According to Svedberg, a considerable reduction in the decomposition of the liquid can be obtained by operating with oscillatory discharges of high voltage and low amperage. In one of the several methods employed by Svedberg, the secondary terminals of an induction coil capable of producing sparks 5 to 6 inches in length were connected in parallel with a condenser and the electrodes. The latter were dipped into a layer of granulated metal covering the bottom of a porcelain basin filled with the required liquid. In this arrangement, vigorous sparking occurred between the metal particles, which led to the production of the colloidal metal, while the electrodes merely served to polarise the metal particles. Svedberg was able to extend this method successfully to the preparation of colloids of materials of low electrical conductivity, such as sulphur, phosphorus, copper oxide, etc. The apparatus used by him for this purpose is outlined in Fig. 1. Here, a glass funnel is provided with a conical metal insert connected to one terminal and containing the material in powder form, while the central electrode dipping into the powder is connected to the other terminal. Svedberg also experimented with discharges between electrodes and measured their loss in weight. This he found to be equal for both electrodes.

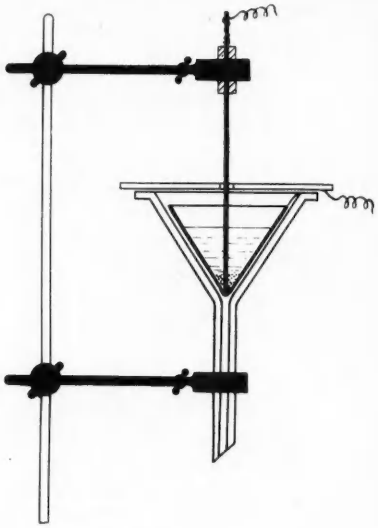

Fig. 1.

In the course of a few years after Bredig's first experiment, the production of metal colloids by the electrical method became widely accepted in laboratory practice, but although various explanations of the nature of the process were suggested, the first systematic investigation was not made until 1919, when Kohlschuetter[3] published a paper giving the results

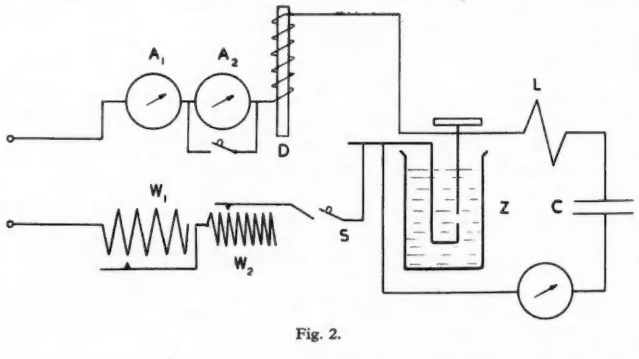

Fig. 2.

of a series of tests which, because of their fundamental importance, must be dealt with in some detail here.

While Svedberg had employed an oscillatory discharge of high voltage and low amperage produced by the insertion of a condenser in parallel with the spark produced by an induction coil, Kohlschuetter's apparatus was operated with direct current of 96-250 volts, the circuit being as outlined in Fig. 2. Here it will be seen that the circuit included two adjustable resistors W_1 and W_2 of a maximum of 45 and 360 ohms respectively. The electrodes were vertically arranged in the container Z. Connected in parallel with the electrodes was a condenser C, while a choke with iron core D was arranged in the main circuit. Ammeters A_1 and A_2 were also provided.

The electrodes, formed of copper wire of 3·5-2·3 mm diameter, were attached to a holder. The container with distilled water in which the electrodes were immersed had to be removed for the purpose of changing the water held in the containers. It was not considered necessary to effect renewal of the water during the operational period, which ranged from 15 to 20 minutes, at the end of which the water container was removed and the colloidal solution transferred to a beaker for settling out large suspended particles.

On operating the apparatus without the condenser, an arc was established, the current being 1·8 Amp when the resistors W_1 and W_2 were adjusted to pass a 3·0 Amp short-circuit current, that is, when the electrodes were caused to make contact with each other. With a 1·8 amp current flow, the weight-loss of the negative copper electrode was found to be 6·6 milligrams in 15 minutes, while the weight loss of the positive copper electrode was only 0·2 mg during the same period. In other words, the wastage of the negative electrode proved to be 33 times that of the positive electrode. On increasing the arc current to 4 Amps—corresponding to a short-circuit current of 5 Amps—the negative electrode showed a loss of 8·8 mg in 15 minutes, while the positive electrode had no measurable weight loss at all.

On placing the condenser in the circuit and repeating the experiment, an oscillating spark discharge resulted, and it was now the positive electrode which sustained a far greater loss in weight than the negative electrode. Thus, for instance, Kohlschuetter found that with an electrode current of 0·1 Amp the loss in weight of the positive electrode was more than 16 times greater than the loss from the negative electrode. In other words, *the establishment of a spark discharge had completely changed the entire phenomenon of electrode wastage.* From his experiments, Kohlschuetter also drew a number of interesting deductions regarding the relationship between the electrical circuit conditions and the production of colloidal metal, the latter being the main purpose of his experiments. In the present connection, where the fragmentation of metals is concerned, it is of interest to note that Kohlschuetter pointed to the possibility of increasing the ratio of metal removed in colloidal size to metal removed in the form of coarse particles by adjustment of the circuit conditions. This is a matter of considerable importance, because the finer the state in which the metal is removed, the closer is the dimensional accuracy obtainable with the process when used for carrying out machining or grinding operations.

It need hardly be pointed out that Kohlschuetter's experiments were conducted with amperages which are far too small to produce a rate of metal removal of the order required in practice. However, this does not detract from the value of his findings regarding the preponderant wastage of the anode in the case of spark discharges of the nature described. To give the spark discharge process a character of practical importance, it is obviously necessary to employ far larger amperages than were employed or ever envisaged by Kohlschuetter. In this respect, the crux of the problem lies in maintaining a spark discharge (as this form of discharge alone produces the desired cutting effect) and to prevent even accidental deterioration into an arc discharge.

It has been known for a long time past that an initial spark will deteriorate into an arc if the amperage is allowed to exceed a certain value. F. Kraus, in his investigations " Regarding the Conditions Under Which It Becomes Impossible for an Arc to Originate "[4], pointed out that with each voltage there is co-ordinated a certain amperage at which the length of the arc becomes zero. However, W. Burstyn[5] appears to have been the first to call attention to the different conditions required for the existence of arc and spark respectively at the contacts of a switch when opening an electric circuit, and also the first one to show that a borderline condition exists which, if transposed in either direction, will change a spark discharge into an arc discharge, or vice versa. Thus, for instance, Burstyn states that with a tension of 36 volts a spark will accompany the opening of a switch if the current interrupted is less than or equal to 3·5 amps, but that an arc will result if this amperage is exceeded. For a potential difference of 220 volts Burstyn gives a corresponding current value of 1·2 amps. These and other figures, which were arrived at with contacts in air, indicate that there exists a maximum wattage which can be interrupted with sparking only. In other words, there exists a parabolic relationship between voltage and current for arcless interruption. A graphic representation of this type is given by Windred[6], and Fig. 3 shows the general appearance of a graph of this kind as applied to the dispersion cutting process. Here it will be seen that in order to ensure sparking operation for each amperage chosen, a limiting voltage must not be exceeded.

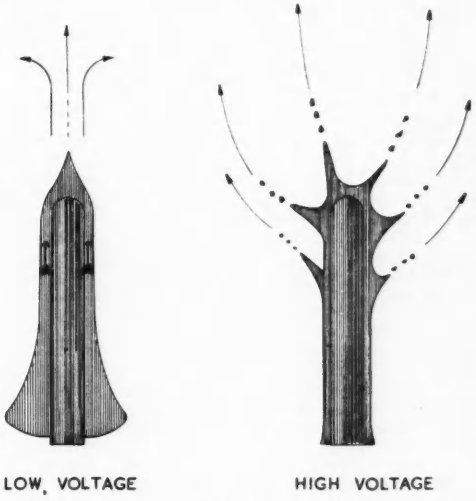

Fig. 3.

As pointed out above, Kohlschuetter's method of colloidal metal production secured outputs measured in milligrams ; it is, therefore, useless as a technological process in modern production. Since the amount of metal dispersed is obviously a function of the wattage available in the spark, a maximum increase in the wattage must be aimed at. This means, however, that the limiting wattage beyond which arcing occurs must be greatly increased beyond the figures given by Burstyn

and others. That this goal cannot be reached by increasing the voltage will be readily appreciated by reference to Fig. 3. Moreover, the employment of high voltages would produce erratic scattered spark discharges, making accurate machining operations quite impossible.

The only way open to higher capacity, therefore, is to increase the limiting amperage for a voltage considered most suitable from the aspects of operating accuracy, safety and economy, etc. The solution lies in

(1) the concentration of the spark discharge at the point of working by carrying out the process of metal removal with the use of an appropriately shaped electrode, this being so designed that the spark discharge is strictly localised and concentrated at the " cutting point " of the electrode,

(2) in the rapid removal of dislodged material from the " cutting zone," and

(3) in the choice of an appropriate bathing fluid and the maintenance of a fluid flow in the cutting zone which establishes the proper conditions for the occurrence of a spark discharge of required intensity under controlled electrical circuit conditions. Additional properties required of this bathing fluid are that it must easily penetrate to the point of cutting (which is of particular importance where deep cuts into thick pieces of metal are to be carried out), and that it must neither produce chilling nor allow heating of the metal. The fact that fragmentation by the spark is not dependent upon the heating of the metal at the position of the cut is particularly favourable in more than one respect.

It will be noted that so far no mention has been made of any requirements with regard to the electrical properties of the bathing fluid, whether it should be an electrolyte or a dielectric. In fact, according to prevailing conditions it may be either an electrolyte or a dielectric or a mixture of both, provided that the electrical conditions are chosen accordingly. Thus, if an oil emulsion is called for in a given case, a higher operating voltage will be required than if an electro-conductive gas is to be used.

Summarising, it may be said that the successful machining of metals by the electro-fragmentation process depends upon the production and maintenance of a set of physical, chemical and electrical conditions so attuned as to produce by spark action the removal of metal particles from the workpiece which forms the positive electrode.

It is interesting to speculate upon the nature of the electro-fragmentation process, particularly as it is so fundamentally different from the action of the electric arc. In fact, the very difference in its manifestations as compared with those of the electric arc may offer a clue to what obviously is an extremely complex phenomenon. An electric arc is generally recognised as a steady-state thermionic phenomenon constituting a type of electric discharge between two electrodes characterised by high current intensity and low voltage drop. A large quantity of electrons is emitted by the intensely heated cathode subjected to high current density and the bombardment by positive ions. In contrast with this, the electric spark possesses a dynamic disruptive quality as its outstanding characteristic. In effect, a spark constitutes a sudden breakdown of the dielectric which separates the electrodes, this breakdown being caused by the formation of ions by an electric field of high intensity. Most obvious evidence for the disruptive and oscillatory nature of the spark are the well-known sound phenomena attending its occurrence. With regard to the mechanical forces released by the spark discharge, it is interesting to note that W. Ostwald[7], in his investigations into the nature and formation of colloids, referred to the fact that static electric charges acting at the interface of two media can produce a negative surface tension in one of the media, which actually leads to the detachment of surface particles in an explosive manner. A typical example is O. Lehmann's[8] experiment with electrically charged molten sulphur in turpentine, where the electrical charge produces the detachment of particles in the manner shown in Fig. 4. As a typical case of surface enlargement of the solid phase and of disperse particle formation, Ostwald cites the formation of spongy lead in accumulator cells. However, the writer is rather inclined to believe that even if these concepts should be applicable to the phenomenon of electro-fragmentation by spark action, oscillatory mechanical forces produced by the spark play an important, if not decisive, rôle in the decomposition into fragments of the metallic surfaces. In this connection it would appear to be significant that recent investigations into various types of surface erosion point to mechanical vibration as the primary cause. Thus, for instance, recent research into the

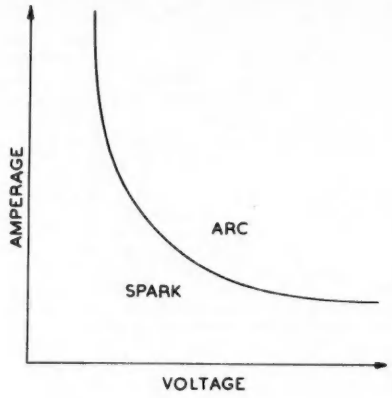

Fig. 4.

mechanism of the cavitation phenomenon points to the occurrence of high localised pressures by water hammer as the likely cause of the erosion process. This would explain why, contrary to other theories of cavitation, erosion does not occur where cavitation bubbles are formed, but occurs at the point where they collapse. The concept of fretting corrosion as a result of vibration and pressure seems to point in the same direction, as do also the effects of high-frequency mechanical vibrations. It is noteworthy that a German war-time patent application claims a process of machining metals by inducing mechanical vibrations at the point of cutting, with frequencies ranging from 100,000 to 1,000,000 cycles per second. In view of the importance attaching to desired as well as undesired metallic decomposition by vibration, fundamental research from this angle would appear to offer considerable scope and should throw light on what today are still obscure and apparently unrelated phenomena.

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(4) F. Kraus, *Elektrotechnik und Maschinenbau*, Vol. 31, 1913 p. 717.

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Noise Problems in Industry

By O. BRANDT. (From *Teknisk Tidskrift*, Vol. 79, No. 9, February 26, 1949, pp. 149-154, 6 illustrations.)

THE apparent loudness of a noise is measured in phons, which are logarithmic units based on the Weber-Fechner law, stating that the auditory sensation is proportional to the logarithm of the excitation energy. Therefore, if the loudness level at a given frequency is raised from 40 to 50 phons, or from 50 to 60 phons, the increase is 10 phons in both cases, and the relative impression of increasing noise is the same. An increase in loudness of 10 phons approximately corresponds to a doubling of the acoustic impression of loudness.

It has been found that a loudness level of 120-130 phons is capable of causing a painful sensation. The question is, therefore, how much lower is the allowable noise level for industrial premises. The effect of noise on working efficiency is related to both physical and psychological factors, and varies with the individual. A high-frequency noise is more objectionable to the average person than a lower frequency noise of the same intensity. Intermittent and variable pitch noises should be avoided as far as possible, particularly where intricate or precision work is being carried out.

According to a French investigation, even comparatively low loudness levels of 75-80 phons are capable of causing a marked decrease in hearing acuity if sustained over a period of 10 to 15 years. For short periods, however, loudnesses of 80-100 phons are tolerable, since a momentary decrease in sensitivity can disappear after the subject has been transferred to a quieter shop section.

If two similar noise sources, each with a loudness of L phons, are situated in the same room, the resultant loudness is $L + 10 \log_{10} 2 = L + 3$ phons. If n such sources are present, the loudness is $L + 10 \log_{10} n$ phons. Thus, when dealing with various machine shop noise sources with the same loudness level, the noise proceeding from each of these sources must be reduced in order to obtain a decrease in the resultant noise. If the noise sources have different loudness levels, a definite improvement is obtained by treating the loudest noise source first. Thus, in making plans for a change-over to new quieter-running machines in a factory, it will be an advantage as regards noise reduction to replace all the machines in one room or workshop in one operation, before proceeding to the next section, instead of replacing a part of the equipment in each different shop.

FACTORY PLANNING FOR MINIMUM NOISE

Noise problems are most effectively overcome in the design stage, when planning new premises. A preliminary survey involves not only a study of the type of building to be set up, but also an investigation of the working processes and methods to be used in the new factory. A comparative study of the noise levels of other factories with installations doing similar work may indicate the most appropriate methods or means for combining efficiency with a minimum of noise. Special noise insulation may be required for certain departments, for instance, laboratories, offices, libraries, etc. Before deciding on the insulation of a room from outside noise, it is useful to have an idea of the amount of noise generated by the machines operating in the room itself, since this noise may be of such a level that it will mask the outside noise.

Good noise insulation of industrial premises can be extremely difficult to achieve. A machine set up directly on the foundations generates both air-borne and structural noise, the latter being propagated with very little damping through the structure of the building. Air-borne noise can be isolated by means of sound barriers, and structural noise by using vibration-insulating foundations.

Industrial buildings with high noise levels can be treated in a similar manner. Direct noise in the neighbourhood of stationary machines is inevitable, but reflected noise can be attenuated by providing suitable deadening surfaces, so that reverberation effects are reduced to a minimum. Furthermore, the machines should be arranged so that the various persons in the room will mainly be exposed only to noise generated by their own machine. However, the overall noise level of a room depends on the number and types of machines operating in it. Modern noise-treated machinery has a minimum of high-amplitude components in the high-frequency region of the noise spectrum, and should not be installed with non-silenced machines which have a higher noise level.

Fig. 1 (left). **Neoprene ear defender designed for insertion in the ear recess (Knudsen and Watson).**

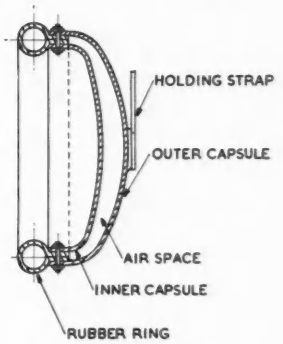


Fig. 2 (right). **Headphone type ear defender (Perwitzschky and Lang).**

A comparison of the various alternative working processes which can be applied to do a given type of work may reveal which is apt to be the most favourable as regards noise. For instance, it is advantageous to use hydraulic machines for plate riveting. Furthermore, processes involving extremely objectionable noise should, if possible, be restricted to certain periods of the day and not be spread over the entire time schedule, the best solution being to alternate a period with noisy processes between quieter periods, avoiding the most noisy jobs towards closing time since they can sometimes prevent complete relaxation after working hours. Delicate persons are particularly sensitive to high noise levels. In the United States, some of the textile factories test the noise sensitivity of their workers, and train their personnel while still engaged on simple jobs to resist continuous noise.

The effect of industrial noise on houses in the neighbourhood of factories also requires consideration. In some districts of Sweden it is required that the noise level inside a house with closed windows should not exceed 40 phons in a noisy area, and 30 phons in a quiet area. Generally, large factories are in separate manufacturing areas, but some of the smaller factories and repair shops are usually near a residential district.

PROTECTION OF PERSONNEL AGAINST NOISE

Persons exposed to high noise levels, i.e., levels exceeding 90 phons, should be provided with special noise-insulating devices, such as the ear defenders

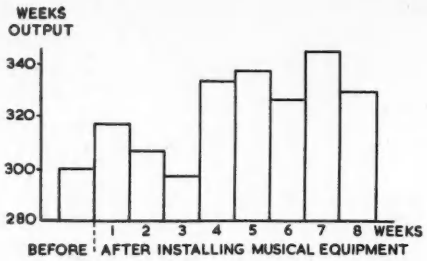


Fig. 3. **Production curve before and after installing musical equipment in an American high-output factory (Burris-Meyer).**

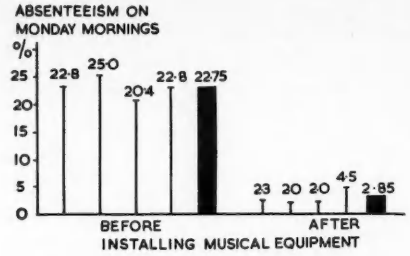


Fig. 4. **Effect of music on Monday-morning absenteeism 4 weeks before and after installing musical equipment (Burris-Meyer).**

shown in Figs. 1 and 2. The ear plug made of neoprene and shown in Fig. 1 gives an attenuation of 35-40 decibels at 1000 cps, which is a very good result. Still higher isolation is useless, since the noise is also transmitted through the bone to the inner ear. The headphone type ear defenders of Fig. 2 are more comfortable to wear. They give an attenuation of approximately 25 decibels. Variants of both types are produced by a number of manufacturers.

USE OF SOUND-ABSORBING MATERIALS

Noise in factory premises can be diminished by using special materials which reduce reflections of airborne noise to a minimum, so that persons within a bay or workshop are only subjected to the direct noise from the machines nearest to them, which masks other noises from more distant sources.

In a room with wall, ceiling, and floor surfaces

$$S_1, S_2, S_3, \ldots \quad \ldots \quad [m^2]$$

having initially the absorption coefficients

$$\alpha_1, \alpha_2, \alpha_3, \ldots \quad \ldots \quad [\text{decibels/m}^2].$$

the reduction of the average noise level obtained by using sound-absorbing materials with the absorption coefficients

$$\beta_1, \beta_2, \beta_3, \ldots$$

is given by

$$R = 10 \log_{10} \frac{S_1\beta_1 + S_2\beta_2 + \ldots}{S_1\beta_1 \quad S_2\beta_2 + \ldots} \quad [\text{db}]$$

(The above formula is also approximately valid for measurements in phons). This means that when, for instance, the absorbing capacity of a room is doubled, the improvement achieved is a reduction of 3 phons only; and a 10 times greater absorption capacity is required to obtain a noise reduction of 10 phons, so that in practice it is reasonable to expect that a decrease of 5 to 10 phons is achievable with this treatment. Thus, sound-deadening materials are not in themselves sufficient to reduce extremely high noise levels to intensities well below the pain level. The results obtained with these materials are partly due to a psychological effect on the listener.

ACOUSTICAL TREATMENT

The acoustical treatment depends on the type of noise source in the room under consideration. If the noise has an impulsive character, as for instance in the case of sudden impact or hammering on metal, the use of deadening materials to damp out the high-frequency reflections will bring about a noticeable improvement. If, however, the noise is fairly constant and continuous, as in the case of electrical machines and transformers, the improvement will not be of the same degree.

Absorbing surfaces are particularly effective in workshops with machines set up some distance apart, where the noise level can be reduced to that due to direct noise. The problem should also be approached in the planning stage, by installing particularly noisy machines in separate rooms, and setting up sound barriers between rooms with noisy machinery and the quieter sections. The effectiveness of the sound proofing depends also on the height of the ceiling. In a room with a high ceiling, a marked improvement can be obtained even with some of the noisiest machines by erecting a sound-absorbing ceiling at a lower level.

The absorbing material chosen should have its optimum absorption characteristic in the range of fre-

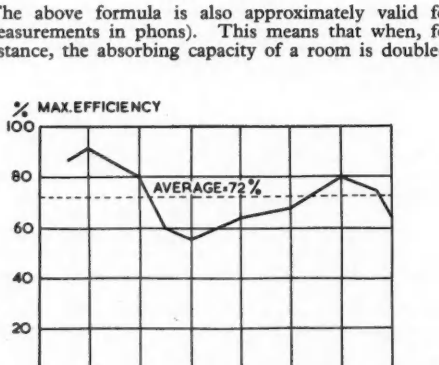


Fig. 5. **Typical production curve for a group of workers before installing musical equipment in factories (Burris-Meyer).**

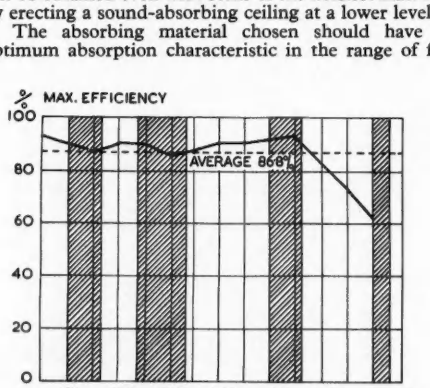


Fig. 6. **Typical production curve for a group of workers under the influence of an appropriately selected programme of music in the factory. Music transmission was stopped during the shaded periods (Burris-Meyer).**

quencies corresponding to the predominant amplitudes in the spectrum of the noise source. Most of the sound-absorbing materials available have a considerably greater absorbing capacity in the region above 600-800 cps, and are therefore effective in reducing high-frequency components which are particularly objectionable to the ear, so that in many cases they are indispensible. For certain types of noise, selective absorbers, or resonators, can be employed to reduce certain frequencies. In the low-frequency range, absorbing materials are not effective to the same extent, and the best way of obtaining a reduction of the low-frequency components of electrical and slow-running machinery is by careful balancing of the machine and redesigning of certain components.

MUSIC IN WORKING PREMISES

In addition to the direct methods of noise reduction, another possibility is that of masking machinery noise with music. Excellent results are obtained, provided the noise level is not extremely high. In order to be heard, the music must be of the same loudness as the background noise, and at very high loudness levels the music is more of a nuisance than it is useful. Music is, therefore, most effective in premises which have already been acoustically treated.

Investigations of the effect of music on workers' output have been carried out in various countries, and particularly in the United States. The favourable results obtained should, however, be accepted with some reserve, as in some cases they are issued by firms interested in the sale of musical equipment. Nevertheless, it does appear that a suitably selected programme may help to stimulate the average individual and increase productivity. Figs. 3-6 give some typical curves showing the effect of music on output, and on absenteeism on Monday mornings. The results are of interest and this method deserves further investigation.

FRANCE

Baths for Copper Plating

By M. J. Salauze. (From *Bulletin de la Société Française des Electriciens*, Series 6, Volume 9, No. 88, January, 1949, pp. 23-30.)

1. Advantages and Disadvantages of Commonly Used Baths

The two types of commonly used copper plating baths, copper sulphate and copper cyanide, have been known and used for over 100 years. Sufficient literature is available on these two types and the following will be confined to remarks essential to an appreciation of the subsequent deliberations.

The advantages of the acid copper bath, which is a mixture of copper sulphate and sulphuric acid, are low cost of the constituent materials, simplicity in use, and little change in concentration during use.

Its disadvantages are (a) its complete incapability of producing adherent deposits on materials which, like iron, are lower than copper in the electrode potential scale; (b) a mediocre power of penetration which, although positive, is very near zero, and which is due to the combined effect of a cathode current efficiency of 100 per cent, and a weak polarisation on the cathode; (c) the absence of any known addition agent for obtaining bright surfaces—except for one agent, which, however, is effective only at an impracticably low temperature; (d) the copper sulphate bath cannot satisfactorily be operated at higher current densities.

It was mainly the inability of the sulphate bath to produce adherent deposits on certain materials, such as iron, which led to the widespread use of the cyanide bath. For nearly one hundred years, this bath has been composed of 50 grams of copper cyanide and one and a half times this amount of alkaline cyanide plus about 20 grams of alkali carbonate. Among the disadvantages of this bath are the low current density obtainable, the extreme variations of the anode and cathode efficiencies, which fluctuate between 20 and 70 per cent, the violent toxicity of cyanide, and the impossibility of producing thick coherent deposits.

Its advantages are first of all, its undeniable degreasing action due to both the alkaline nature of the bath and the liberation of hydrogen during the deposition of the copper, and an excellent penetration; the latter is due to the fact that at the salient parts of the cathode the potential is at a maximum, while the current efficiency is at a minimum.

For the last hundred years these two baths were being used more or less in accordance with their original formula, and no new type of bath appeared. It seemed, therefore, that the technique of copper plating had reached finality. However, during the last ten years a considerable transformation has taken place in the field of copper plating, the causes being:—

(i) the desire to exploit the cyanide bath to the highest possible degree, as soon as such a possibility was recognised.

(ii) search for compositions which would not contain cyanide, but which, nevertheless, would be suitable for depositing copper directly on iron or zinc.

(iii) search for compositions by means of which bright surfaces could be obtained, or which could be used with very high current intensities.

2. Modernisation of the Cyanide Bath

(a) *The old-type composition; research by Pan.*

Until very recently, the cyanide bath had not been subject to sufficient scientific research and the following was given as a good average composition of the bath:

Copper cyanide	..	27 grams/litre*
Sodium cyanide	..	36 „
Sodium carbonate	..	16 „

It was only in 1935 that Pan began to study a concentrated bath, using a gram-molecule of copper cyanide per litre. This bath had the following composition:

Copper cyanide	..	90 grams/litre
Sodium cyanide	..	122 „
Sodium carbonate	..	44 „

Pan, who operated the bath at only 22° C, reached a current density of 3·5 amp/dm² (1 amp/dm² = 9·2 amp per sq. ft.); when the bath contained 10 grams of free cyanide per litre and operated at 2 amp/dm², anode and cathode efficiencies of 80 per cent could be reached.

(b) *Research by Du Pont de Nemours.*

Pan's researches were carried further by Du Pont de Nemours' scientists, who took the important step of increasing the temperature, thereby creating the

* 1 gram/litre = 6·25 oz. per Brit. Imp. gal.

modern copper plating bath. They were able to reach cathode and anode efficiencies of nearly 100 per cent. This resulted in a better equilibrium of the bath, and in the possibility of obtaining high-gloss deposits. Finally, the anode efficiency was brought to practically 100 per cent, despite the free cyanide contents being almost nil. This resulted in an extremely small decomposition of cyanide through anodic oxidation, and the bath could be brought up to high temperatures and still remain stable.

The composition of the bath is as follows:

Copper cyanide	90 to 150	(optimum	120)	grams/litre
Sodium cyanide	100 to 170	(„	135)	„
Caustic soda	22 to 38	(„	30)	„
Addition agent	11 to 19	(„	15)	„
Anti-porosity agent ..	1·2 to 1·8	(„	1·5)	„

From this it is easy to calculate the free cyanide content, which is only 3·75 grams/litre, if it is assumed that the double (copper and sodium) cyanide can be described by the formula $Na_2 Cu (CN)_3$. It is assumed, however, that at high temperatures the following reaction takes place:

$$Na_2 Cu (CN)_3 = Na Cu (CN)_2 + Na CN$$

which results in the formation of free cyanide.

According to the corresponding patents, the addition agent for the production of high-gloss coatings is sodium sulphocyanide and the anti-porosity agent betaine, a cyclic amino compound having a non-cyclic chain with 10 to 20 carbon atoms. The action of this compound is due to a lowering of the surface tension of the bath. It seems, however, that the use of sulphocyanide has actually been abandoned, and that a new addition agent is being used, which produces a high gloss and simultaneously acts as an anti-porosity agent. Finally, Du Pont de Nemours seem at present to give preference to potassium salts; the new composition of their copper bath is:

Copper	..	42	grams/litre
Free cyanide	..	3·75	„
Potassium	..	42	„
Addition agent	..	2	„

The advantages of this substitution are the reduction by one half of the copper concentration in solution in the bath, the possibility of obtaining deposits of a thickness of 0·075 mm, and a lower consumption of cyanide, as the potassium salt is more stable than the sodium salt.

Either bath is used at a temperature of 80 to 85° C, and current efficiencies of 100 per cent can be maintained. This requires close supervision of the free cyanide concentration; if it is too high, the cathode efficiency deteriorates and the deposits become matt. If it is too low, the anode becomes polarised. The cathode current density lies between 1 and 6 amp/dm²; it can reach 13 amp/dm² if the agitation of the bath is sufficient. In any case, agitation is necessary, but the method of blowing air through the solution cannot be used.

In spite of all its advantages this bath has two faults. First, its power of penetration is only mediocre, due to the current efficiency being nearly 100 per cent at any point of the cathode. Secondly, plating of iron must be commenced in a bath of the old composition; this is necessary in order to avoid a layer of insufficient adhesive strength which would be produced through chemical displacement if the object were placed directly in the new bath.

(c) *Rochelle salt bath.*

Although this bath was introduced for copper plating in 1857, it was not until 1938 that it was perfected, and the following was given:

Copper cyanide..	19 to 45	(optimum	26)	grams/litre
Sodium cyanide	26 to 53	(„	35)	„
Sodium carbonate	15 to 60	(„	30)	„
Rochelle salt ..	30 to 60	(„	45)	„

Caustic soda to produce a pH of 12·2 to 12·8 (optimum 12·6).

This bath can produce high-gloss surfaces. However, sulphite, bisulphite, and hyposulphite, as addition agents, are not stable, and their decomposition products may lead to coarse deposits. An addition of 0·015 to 0·030 grams/litre of sodium plumbate, therefore, seems preferable.

The operating conditions of this bath are as follows:

(i) cathode current density 2 to 6 amp/dm², maximum 7·5 amp/dm²;

(ii) bath temperature 50 to 80° C, preferably 55 to 70° C, to avoid acceleration of the decomposition of the cyanide; cathode efficiency 30 to 70 per cent;

(iii) the anode current density must be maintained at about half the cathode density, whereby anode and cathode efficiencies are made equal;

(iv) agitation improves the efficiency;

(d) *Comparison of the three cyanide baths.*

From the foregoing it can be seen that in medium-size plating installations, it will be advisable to keep to the old-type bath, as the other two baths, if not perfectly applied, will produce rejects. In a well-equipped and properly supervised installation, the bath of Du Pont de Nemours will find a unique place, and will produce exceptionally good results; it seems preferable to the Rochelle salt bath, which, nevertheless, has established itself in the industries of both the United States and Great Britain.

3. Bath Designed to Replace the Cyanide Baths.

Due to the very high toxicity of cyanides, attempts have been made on different occasions to find a substitute which would not only allow the direct deposition of copper on iron, but also lend itself to the production of high-gloss surfaces.

(a) *The oxalate bath* of 20 grams/litre copper oxalate, 75 grams/litre sodium sulphate, 20 grams/litre boric acid, first introduced in 1933, is interesting, as it was the first instance of an oxalate being used for such a purpose. However, only very thin deposits can be obtained.

(b) *Amino baths.* The amines used in the investigations from 1937 to 1938 were the mono–, the di–, and the tri-ethanolamine, respectively:

$$N \lessdot \begin{matrix} H \\ H \\ CH_2\,CH_2\,OH \end{matrix}$$

$$N \lessdot \begin{matrix} H \\ CH_2\,CH_2\,OH \\ CH_2\,CH_2\,OH \end{matrix} \qquad N \lessdot \begin{matrix} CH_2\,CH_2\,OH \\ CH_2\,CH_2\,OH \\ CH_2\,CH_2\,OH \end{matrix}$$

If one of these amines is added to a copper sulphate solution, a precipitate is formed which dissolves again in an excess of the amine. In this way, clear deep blue solutions are obtained. For practical purposes, i.e., for obtaining bright deposits of good adhesion strength, sodium oxalate must be added to any of the three amino baths. A characteristic composition of a monoethanolamine bath is as follows:

Crystallised copper sulphate ..	..	76 to 149	grams/litre
Sodium oxalate	..	25 to 50	„
Monoethanolamine	..	77 to 151	„

In this case, at normal room temperatures, cathode current densities of 11·6 amp/dm² can be reached. No chemical displacement is produced with iron, and when using diethanolamine, cathode efficiencies in the neighbourhood of 100 per cent can be obtained.

The following are the compositions of two baths of still more recent origin, using diethylene-triamine

NH_2–CH_2–CH_2–NH–CH_2–CH_2–NH_2:

Crystallised copper sulphate ..	50 grams/litre
Diethylene-triamine ..	35 cm³/litre, and
Crystallised copper sulphate ..	100 grams/litre
Diethylene-triamine ..	80 cm³/litre
Ammonium sulphate ..	20 grams/litre

The latter bath operates at 60° C with an average cathode density of 4·3 amp/dm² which can reach a maximum of 14 amp/dm². Laminated copper plate is used for anodes and the anode current density must not exceed 1·7 amp/dm². Iron and zinc objects must be pre-treated in a copper cyanide bath. This shows that, at least for this application, the cyanide bath could not be dispensed with, but, on the other hand, a brilliant copper deposit was obtained, which did not require any subsequent polishing.

(c) *Pyrophosphate bath* (*Starek*). This bath is in industrial use in the United States. The composition in which the copper is contained is a double pyrophosphate of both copper and an alkali. The following are two (patented) solutions:

Soldium Salt:

Copper sulphate ..	200 grams/litre
Sodium pyrophosphate ..	200 „
Sodium chloride ..	30 „

Potassium salt:

Copper pyrophosphate ..	110 grams/litre
Potassium pyrophosphate	404 „
Ammonia	3 „
Citric acid	10 „

These two baths produce directly adhering deposits on zinc and iron, which, in addition, are glossy. The pH of the bath must be between 7·5 and 9. The current efficiency is in the neighbourhood of 100 per cent. The bath temperature may be between 27 and 54° C. The sodium chloride and the citric acid are added to increase the gloss of the deposit. The cathode density increases with temperature, agitation and concentration of the salt. To obtain high-gloss surfaces, it is advisable to maintain current densities low, at about 1 amp/dm².

(d) *Sulphamate baths*. The solutions of the salts of sulphamic acid HSO_3NH_2 seem to offer interesting possibilities in the field of plating, as they lend themselves for use as baths for the deposition of lead, zinc, silver, cadmium, nickel and cobalt. For copper plating, the following baths can be used:

Copper sulphate	130 grams/litre
Ammonium sulphamate ..	100 „
Soda	7·5 „

At 35° C this bath sustains current densities up to 3·8 amp/dm² and produces brilliant surfaces of good appearance. The future development of the sulphamate bath, knowledge of which is still rudimentary, cannot be predicted and will depend to a large extent on the price of sulphamic acid.

4. Baths to Replace Copper Sulphate.

One of the disadvantages inherent in copper sulphate baths is the comparatively low solubility of copper sulphate, which, in turn, adversely influences the current densities obtainable and, consequently, the time necessary for obtaining the required deposit. For this reason, two new types of baths have been investigated: one based on copper fluoborate which has already shown practical results, and the other based on sulpho-derivatives of carbohydrates of the methane group, but which is of too recent origin to allow of commenting on its likely prospects.

(a) *Copper fluoborate baths*. The advantage of these baths is due to the very high solubility of copper fluoborate; this allows of making very concentrated solutions, which, in turn, make very high current intensities possible. Of the various possible compositions, the following is commercially obtainable:

Copper fluoborate $Cu(BF_4)_2$	693 grams/litre
Fluoboric acid HBF_4 ..	46 „
Boric acid H_3BO_3	46 „

The optimum current densities for this type of bath, without agitation, are, in amp/dm²:

Copper concentration 60 grams/litre:
15 (25° C), 26 (50° C).

Copper concentration 120 grams/litre:
31 (25° C), 37 (50° C).

The fluoborate bath produces fine deposits of good appearance which are easily polished. The cathode and anode efficiencies are very nearly 100 per cent. The concentration of the free fluoboric acid can be varied without great inconvenience. The resistance is low, but somewhat higher than that of copper sulphate baths. It is to be hoped that further research will be made to determine the possibilities of this bath, into which as yet little investigation has been made, and that copper fluoborate will be put on the market at an acceptable price.

(b) *Alkylsulphonate baths*. These consist of mixtures of the sulphonic acids of methane, ethane, propane and butane. They conform, therefore, to the formula $C_n H_{2n+1} SO_3 H$, with n representing the numbers 1 to 4. This mixture of acids is mixable with water and is very stable below 100° C. It is as a rule a liquid of density 1·35, containing 92·7 per cent sulphonic acids, 3·2 per cent sulphuric acid, and 4·1 per cent water. Its molecular weight is 113.

Copper alkylsulphonates are very easily soluble in water, so that baths can be produced containing 100 grams of metal per litre. Such baths allow extremely high current densities without producing burned deposits. With agitated baths the following results were obtained:

	Bath No. I	II	III
Copper (grams/litre)	25	50	100
Free alkylsulphonic acid (grams/litre)	5–10	5–10	5–10
Max. current density at 49° C (amp/dm²)	16	37	75
Practical range of current density at 49° C (amp/dm²)	2–10	10–27	25–65
Max. current density at 65° C (amp/dm²)	22	43	130
Practical range of current density at 65° C (amp/dm²)	2–15	10–32	52–86
Ratio of anode to cathode surface	1 : 1	2 : 1	4 : 1

The conductivity of these baths is good, although it is somewhat below that of fluoborate baths. The penetration power is also good. Sufficiently glossy deposits can be obtained even without the use of addition agents, if the current density is near the upper limit. With bath No. III, brilliant deposits can be obtained at 32° C, even if the density is only just over 5 amp/dm². It is possible to produce fine grain deposits of 0·13 mm thickness; beyond this the grain increases. The crystals are small and show no orientation.

The ductility of the deposit decreases with the temperature. If thick deposits are required, an operating temperature of 60 to 65° C is recommended.

If this type of bath is to become adopted in industrial practice, it will be necessary to make the required constituents readily available at reasonable cost. Its prospective uses will become interesting when addition agents have been found for producing mirror surfaces and for avoiding tree formation on thicker deposits.

ITALY

Investigation of Cavitation Corrosion

By G. PETRACCHI. (From *La Metallurgia Italiana*, Vol. 41, No. 1, January-February, 1949, pp. 1-6, 5 illustrations.)

CORROSION due to cavitation occurs in marine propellers, hydraulic machines, condensers, etc. Various theories have been evolved to explain this process. Cavitation corrosion is a phenomenon characterised by the fact that the liquid detaches from, and then impinges upon, the surface of the specimen. This is accompanied by the formation of vacuum pockets within the liquid, the liberation of gases normally dissolved in the liquid, and local corrosion of the specimen.

With regard to testing equipment, extensive use has been made of an apparatus comprising a tube of nickel, subjected to longitudinal vibrations by magneto-strictive excitation. The specimen is fixed at one end of the tube and immersed in the liquid in which the effect is being studied. Another apparatus is the shock-wave generator developed by Ackeret. With this the shock-wave effect in the liquid can be investigated separately, without the additional influence of the oxygen liberated in the cavitation process. Tests of specimens mounted on tuning forks have also given good results. The main requirement is to have a sufficiently high vibration velocity. A tuning-fork apparatus used by the author had a vibration velocity of 5 m/sec at 800 cps.

Interesting results with jet-type equipment have been obtained by Mears, using a wheel rotating with a peripheral velocity of 90 m/sec. The metal specimens are mounted on the wheel periphery and subjected to a fine jet of water. The drawback of this arrangement is that, after corrosion begins, the profile of the test surfaces is altered, so that the angle of impact of the liquid may be different for each specimen.

Various explanations of the observed facts have been given. Thus, according to Evans, cavitation causes destruction of the material as a result of combined action of chemical and mechanical influences, which assist one another, so that it would be pointless to investigate these influences separately. Poulter considers that the effect is mainly mechanical, the water being compressed in the pores of the metal at a pressure sufficient to break down the walls of the porosities when it is not counterbalanced. He found, for instance, that metal surfaces covered with oil prevented penetration of water and eliminated corrosion. Other investigators state that corrosion occurs only if pressure exceeds a certain value. In fact, the corrosive effect is not measurable at very low spray pressures, and the curves showing the weight losses in relation to the time elapsed are similar to Wöhler curves for given fatigue stresses. Beeching suggests that cavitation gives rise to stresses which would be destructive in any case, and that this action can be accelerated by the effect of a corrosive medium. In the discussion of Beeching's work, Drysdale mentions the fact that galvanic coupling renders the surfaces more vulnerable to "bombing" attack, and also refers generally to the effect of surface roughness, but Beeching tends to regard the influence of galvanic currents as a secondary effect.

However, if cavitation corrosion were predominantly a mechanical effect, there should be normally a relation between mechanical fatigue strength and the cavitation effect. This is not so, although the correlation is apparent for alloys of the same type and chemical composition. Other investigators, working on the assumption that the effect is purely mechanical, have found that cavitation resistance is greater the higher the figure of merit is for the material tested. This figure of merit is defined as the product of the load at rupture and elongation at rupture. These investigators have not, however, explained why the combined effect of corrosion and mechanical stress produces an overall result which is much greater than the sum of the two effects acting individually.

In contradistinction to the above theories, it should be remembered that Ramsay, 36 years ago, observed that when metals are subjected to mechanical stresses, their solution potential is altered, owing to galvanic currents between adjacent areas of the same specimen under flexural load. Ramsay, therefore, came to the conclusion that the vibration and general flexural condition of marine propellers produced currents with corrosive effects. Furthermore, in more recent years, Giuliotto determined the variation of the solution potential of iron as a function of tensile stress. There is no reason why this positive result should not also be applicable to all types of alloys and metals.

HYPOTHESIS ON THE FUNDAMENTAL CAUSES OF CAVITATION CORROSION

A comparison of the results described above led the author to consider whether a major effect producing cavitation corrosion could not be attributed to currents giving rise to an anodic attack. This anodic corrosion may be due either to external causes, such as stray currents or galvanic coupling, or to internal causes, such as minute galvanic cells formed in the metal as a result of localised mechanical stresses, or of the liberation of oxygen during cavitation. Temperature differences, and the sudden compression of gases which fill the bubbles initially formed by cavitation, may also be contributory factors to the formation of these currents.

Regarding the mechanical stresses, in particular, it can be asserted that the currents set up between adjacent crystals increase the corrosive action owing to one or several of the following causes :—

1. The deformations due to mechanical stresses increase the e.m.f. of the microcells, by altering the internal energy of the small surfaces constituting the electrodes ;
2. the polarisation of the microcells can be slowed down or even impeded by varying stresses ;
3. the corrosive effect is localised in the most highly stressed areas (owing to 1.), and therefore it increases the stresses and accentuates deformation. Microcells with even very low e.m.f. values can give rise to appreciable effects, resulting in superficial crystalline corrosion at highly stressed points. In these weakened positions, the effect of mechanical shock is much more considerable, and increases the efficiency of the microcells.

In order to justify these considerations, experimental evidence was required so as to prove that :—

1. by preventing the flow of local currents a favourable effect is obtained on fatigue and corrosion resistance combined, and on cavitation corrosion ;
2. by increasing these currents, the destructive effect of cavitation increases and reduces fatigue resistance.

The effect of the microcells can be neutralised by using the entire specimen as a cathode. It can be increased by using the specimen as an anode, and superimposing an external current producing anodic attack. In order to be convincing, the tests should show that even currents of very low intensity are capable of having a decisive effect.

DESCRIPTION OF TESTS

Owing to lack of sufficient means, it was not possible to carry out tests on large numbers of alloys of different types. The results of two main series of tests on various materials are given in the following lines.

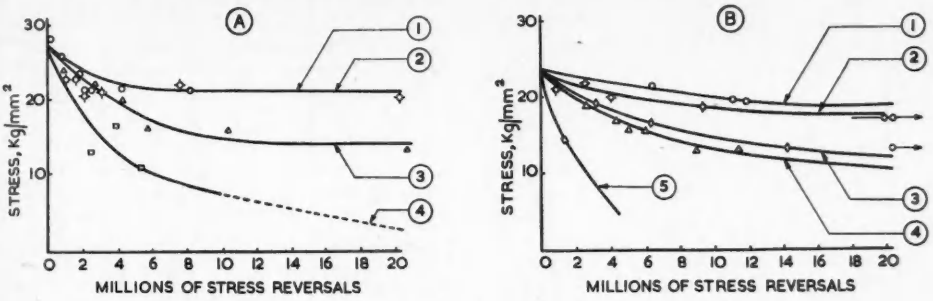


Fig. 1

(4) " A " type specimen in sea water, with a current density of 1 mA/cm². Positive voltage applied to test specimen.
(1) " A " type specimen in sea water, with a current density of 1 mA/cm². Negative voltage applied to test specimen.
(3) " A " type specimen in sea water.
(2) " A " type specimen in air.

Fatigue corrosion tests. A number of Muntz metal specimens were taken from two different bars " A " and " B." A rotary bending machine was used, with the cantilever specimens clamped at one end. The specimens were subjected to a jet of sea water, while rotating at a speed of 3,000 rpm. The results obtained are shown in Fig. 1, and lead to the following conclusions :—

" A " specimens : Using the specimens as cathodes, a current density of 1 mA/cm² was sufficient to neutralise the corrosive effect of the sea water, and to obtain a fatigue curve similar to that for air (see curves 1 and 2). Anode attack with a current density of 1 mA/cm² had a decisively destructive effect (curve 4), and roughly doubled the effect obtained by combined action of mechanical stress and sea water corrosion (curves 3 and 4).

(5) " B " type specimen in sea water, with a current density of 10 mA/cm². Positive voltage applied to specimen.
(1) " B " type specimen in sea water, with a current density of 10 mA/cm². Negative voltage applied to specimen.
(4) " B " type specimen in sea water, with a current density of 0·1 mA/cm². Positive voltage applied to specimen.
(3) " B " type specimen in sea water.
(2) " B " type specimen in air.

" B " specimens : Tests on these specimens confirmed the results previously obtained. A marked deterioration was achieved even with a very weak anode attack, as is evident from the comparison of curve 2 (specimen tested in air), curve 4 (anode attack with a current density of 0·1 mA/cm²), and curve 3 (effect of sea water alone).

Marked cathode protection (see curve 1) was obtained with a current density of 10 mA/cm². The material thus protected had a fatigue strength higher than that of the specimens tested in air. The specimens were tested in air as usual, without oiling, in a coastal and industrial atmosphere (Naval Arsenal of La Spezia).

Cavitation tests : The specimens were tested in pairs in a specially designed nozzle-type apparatus, comprising (1) a pump, supplying water to the nozzle at 1·5 atm. pressure, (2) a nozzle, arranged in the water jacket of rectangular cross-section containing the

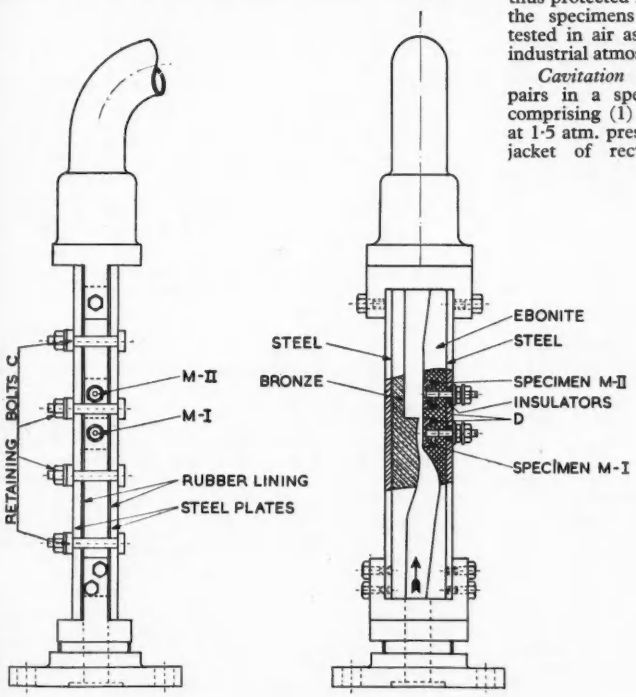


Fig. 2. **Cavitation testing apparatus.**

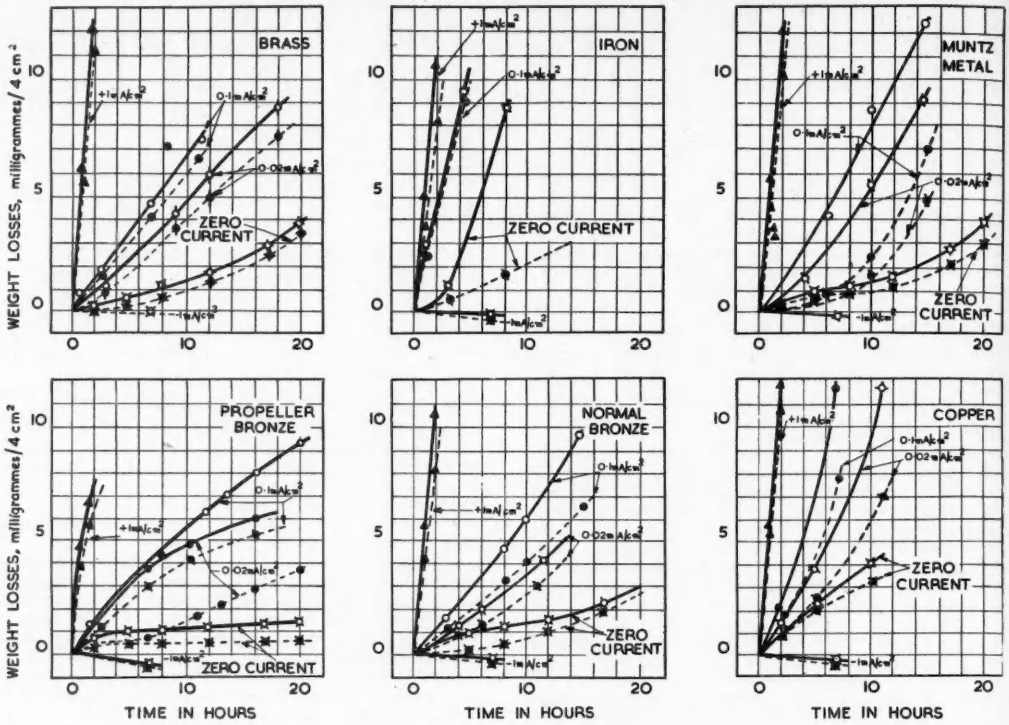


Fig. 3. **Results of cavitation tests.**

specimens, and (3) an outflow tube, discharging the water coming from the nozzle into a water tank. The main portion of the apparatus is shown in Fig. 2.

The two highly-polished specimens (marked D in Fig. 2), with an area of 20 × 20 mm exposed to cavitation attack, were fixed in position by means of dove-tailed holding members bolted to the sides of the water jacket, which was lined with rubber sheets mounted on steel plates. The bolts securing the holding members also served as terminals for the positive or negative voltages applied to obtain anode corrosion or cathode protection, the voltage of opposite polarity being applied to the nozzle mass. The materials tested included bronze, propeller bronze, iron, Muntz metal, brass and copper specimens.

The test results are shown in Fig. 3. The solid lines refer to specimens fixed in position M-I, and the dotted lines to specimens in position M-II. The conclusions can be summed up as follows :—

1. In all the tests carried out, it was found that the specimens fixed in M-I showed less corrosion than those in M-II. This difference can be attributed to the fact, confirmed by examination of the specimens, that the test surfaces in position M-I were more or less irregularly covered with thin layers which generally produced interference patterns. The presence of these protective films may be due to the fact that the water reaching the specimens M-II had already given up its oxygen content, or that the cavitation effect was less active at that position. The film was particularly pronounced on the iron specimens.

2. All the alloys tested were corroded to a much greater extent when tested as anodes than when otherwise tested, even when the anode current density barely reached 0·02 mA/cm².

CONCLUSIONS AND OUTLINE OF FURTHER RESEARCH WORK

With regard to cavitation corrosion, the major factor is that the specimen can operate as an anode and as a cathode. The electric currents are generated by microcells formed in adjacent crystals, as a result of the alternating mechanical stresses and the motion of the liquid. This assumption is in agreement with the results previously obtained by Poulter, who operated under conditions which prevented the formation of local currents. Other influences may also play a part, but these factors did not intervene in the tests with fatigue and corrosion combined, in which the effect of the currents was in all respects similar to that observed in cavitation tests.

In conclusion, it can therefore be said that cavitation is not initially destructive because of the mechanical stresses to which it gives rise, but because these stresses are associated with a corrosive action which is primarily due to electrical effects.

Further research work will have to be carried out into the protective effect of cathode coupling, with much higher current densities than those previously mentioned, in order to establish experimentally the limiting values for which destruction of the metal occurs as a result of mechanical fatigue. A study is also required of the effect of the vacuum pockets which presumably give rise to much higher potentials than the metal surfaces.

Investigations should furthermore be made of the variations of the current passing through the specimen during each stress reversal, and it will be of interest to endeavour to separate the effect of corrosion due to the liquid from that due to the electrical potential. Tests in accordance with this programme are now in progress, and will be described at a later date.

Fundamentals of Automatic Control

By W. OPPELT. (From "Fundamentals of automatic control," *Wolfenbütteler-Verlagsanstalt G.m.b.H.*, Hannover, 1947, 118 pp., 32 illustrations; "Graphical methods for complex multiplication," *A.E.Ü.*, Vol. 2, 1948, pp. 76-78, 4 illustrations; "New methods for assessing the stability of automatic control processes," *Die Technik*, Vol. 3, No. 7, July, 1948, pp. 312-314, 7 illustrations.)

(*Concluded from July issue*)

12. STABILITY CONDITIONS

A system is statically stable when it reverts to its equilibrium position after a disturbance. It is dynamically stable when the system comes to rest again after a disturbance without giving rise to vibrations of increasing amplitude about the equilibrium position.

The stability limit is the limit at which there is a transition between vibrations of decreasing and increasing amplitude. The stability limit is therefore characterised by constant-amplitude vibrations.

Stability conditions can be formulated for the differential equations of the closed loop, the loci and transient functions of the open loop, and the loci of systems subjected to reference-datum variations and external disturbances.

(a) *Hurwitz Criteria*

The differential equation (36) of the closed-loop system can be re-written as follows:—

$$a_n \varphi^{(n)} + \ldots + a_2\varphi'' + a_1\varphi' + a_0 \varphi = 0 \quad .. \quad (57)$$

According to Hurwitz, the system is stable if (1) all the coefficients a_n exist and have the same sign prefixed; and (2) if all determinants of the type

$$\begin{vmatrix} a_{n-1} & a_{n-3} & a_{n-5} & \cdots & \cdots \\ a_n & a_{n-2} & a_{n-4} & \cdots & \cdots \\ 0 & a_{n-1} & a_{n-3} & \cdots & \cdots \\ 0 & a_n & a_{n-2} & \cdots & \cdots \\ 0 & 0 & a_{n-1} & \cdots & \cdots \\ 0 & 0 & a_n & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots \end{vmatrix}$$

are positive.

(b) *Stability Conditions according to Cremer-Leonhard*

The algebraic equation obtained by expanding the Hurwitz determinant can only be solved approximately and after a considerable amount of computing work for higher-order equations*. A simpler set of criteria has been established independently by L. Cremer† and A. Leonhard.††

To apply the Cremer-Leonhard stability criteria, the controlled quantity is assumed to be a sinusoidal vibration $\varphi = \varphi_0 e^{i\omega t}$. This expression for φ is then substituted in eq. (57) which gives the characteristic algebraic equation. This characteristic equation of the control process is now plotted as a curve in a co-ordinate system. The vectors $a_1(i\omega)$, $a_2(i\omega)^2$, ... for a given value of ω can be represented as vectors constituting a vector polygon. This polygon is not closed, since eq. (57) is not generally satisfied by a harmonic oscillation unless the locus of the process is situated right on the stability limit. The remainder vector

$$H(i\omega) = a_0 + a_1(i\omega) + a_2(i\omega)^2 + a_3(i\omega)^3 + \ldots \quad (58)$$

can be represented as a locus varying with ω. This $H(i\omega)$ curve must then fulfil the following conditions for stability:—

(1) the curve should not begin at the origin, but at the point $a_0 \neq 0$ on the real axis;

(2) when ω varies from 0 to ∞, the curve of an n-th order equation must pass through n quadrants in the counter-clockwise direction.

If the order of the equation is not known, conditions (1) and (2) can be replaced by

(3) the phase angles of the H-locus must increase steadily with frequency, and the initial amplitude should not be equal to zero.

In general, it is not necessary to plot the locus. It is sufficient to determine the intersections of $H(i\omega)$ with the real and the imaginary axis (equating to zero the imaginary or the real part of eq. (58)), to see whether the curve fulfils the conditions (1), (2), or (3).

The Cremer-Leonhard criteria can be applied to determine the stability of lag networks. The inverse locus $1/\boldsymbol{F}(i\omega) = 1 + T_1(i\omega) + T_2(i\omega)^2 + \ldots$ has the same form as eq. (58). Criteria for the inverse function remainder curve $1/H(iw)$ then are

(1) the $1/H(i\omega)$ curve must begin on the real axis but not at the origin;

(2) the curve for an *n-th* order equation must pass through n quadrants in the clockwise direction, and must not approach the origin along the axis closing the n-th quadrant.

(c) *Criteria for the General Controller Element.*

The network element now comprises lag- and input-control devices. The curve may in this case intersect the same axis several times in succession. The transfer function is

$$\boldsymbol{F}(i\omega) = \Sigma r_n(i\omega)^n / \Sigma T_i(i\omega)^i \quad .. \quad (59)$$

There are three cases:

$i > n$: when $\omega \to \infty$ the denominator is preponderant, and the amplitude tends towards zero, and in case stability exists the total resultant rotation is negative when ω varies from 0 to ∞;

$i = n$: when $\omega \to \infty$ the fraction has a finite value, the amplitude is then also finite, and the phase is either 0° or 180°;

$i < n$: when $\omega \to \infty$ the numerator is preponderant, the amplitude becomes infinite, and the phase is given by the preponderant term.

In practice only case 1 ($i > n$) can be achieved, because in cases 2 or 3 the energy transmitted with the output quantity would become infinite with $\omega \to \infty$. The following necessary and sufficient conditions can now be formulated:

A controller element is stable provided (1) that its locus $\boldsymbol{F}(i\omega) = \varphi_a/\varphi_e$ begins on the real axis but not at the origin; (2) that the curve ends at the origin when $\omega \to \infty$; (3) that the point of infinity in the complex plane is situated to the left of the curve portion going towards higher frequency values; and (4) that the phase angle swept through is negative when ω varies from 0 to ∞. These general criteria can also be applied to the reference-datum or disturbance loci of the entire control system since the system behaves as a single element when subjected to command variations or load disturbances.

*See L. Collatz: The Horner method for complex roots of algebraic equations, "Zeits. angew. Math. Mech.", Vol. 20, 1940, pp. 235-236.

†See "Zeits. angew. Math. Mech.", 1947, No. 2.

††See "Archiv f. Elektrotechnik,", Vol. 38, 1944, pp. 17-28; a further reprint of a previously restricted report by L. Cremer will appear shortly in "Ingenieur-Archiv." Similar conditions are given by A. Lüthi in "Escher-Wyss Mitteilungen", Vol. 15/16, 1942, p. 90, and "Schweiz. Bauztg.", Vol. 119, 1942, pp. 171-174).

When the controller element is determined by its inverse transfer function, its stability is ensured provided (1) that the inverse locus $1/\boldsymbol{F}\ (i\omega)$ begins neither at infinity nor at the origin, but ends at the origin; (2) that the origin is situated to the left of the inverse locus followed in the direction of increasing frequencies; and (3) that the phase angle swept through between $\omega = 0$ and $\omega = \infty$ is positive.

Equation	Critical frequency	Stability condition
Cubic ..	$\omega_k^2 = a_1/a_3 = a_o/a_2$	$a_o a_3 - a_1 a_2 < 0$
Quartic ..	$\omega_k^2 = a_1/a_3$	$a_4 a_1^2 + a_o a_3^2 - a_1 a_2 a_3 < 0$
Fifth-order equation	$\omega_k^2 = \frac{1}{2a_5}[a_3 \pm \sqrt{a_3^2 - 4a_5 a_1}]$	$(a_3 a_4 - a_2 a_5)(a_1 a_2 - a_o a_3) - (a_1 a_4 - a_o a_5)^2 < 0$

The above stability criteria are based on considerations of the transfer function as a conformal transformation $w\ (u, iv) = \boldsymbol{F}\ (z)$ of the $z = (\delta, i\omega)$ plane (where δ = decrement of the oscillation). Each complex locus plane has a critical point w_k. If the considered locus passes through this point, sustained oscillations will occur; the corresponding curve, therefore, defines the stability limit. All eigen-values or solutions of the differential equation are represented at this point, and they must for stability have a negative real part, i.e., they must be situated to the left of the positive imaginary axis $i\omega$ in the $z = (\delta, i\omega)$ plane, when this plane is gone over in the sense of increasing frequencies. The critical point w_k must also then be situated to the left of the locus in the $w\ (u, iv)$ plane, although this is not absolutely valid in the case of many-valued image-functions. The following table gives the critical point of various systems and loci, as well as the criteria to which it is related.

System	critical point w_k	criteria
Open loop ..	$\boldsymbol{F}\ (i\omega) = 1$	Nyquist
Closed loop ..	$\boldsymbol{H}\ (i\omega) = 0$	Cremer-Leonhard
Inverse reference-datum locus ..	$1/\boldsymbol{F}_\psi\ (i\omega) = 0$	„ „
Inverse load-disturbance locus	$1/\boldsymbol{F}_\sigma\ (i\omega) = 0$	„ „

(d) *Stability Limit.*

In practice it is seldom the case that all the coefficients $a_o, a_1, a_2, \ldots$ are given, so that the question is to determine whether the system is stable or not. In general, some of the coefficients which depend on the controller adjustment are capable of assuming any arbitrary value. The problem is then to determine the limits within which these coefficients are variable without impairing the stability of the controller circuit. These limits can be determined by means of the Hurwitz criteria, given under sub-section (a) above. It is simpler, however, to determine the relations which must exist between the coefficients at the stability limit, i.e., in order to obtain constant-amplitude vibrations.

If a sustained oscillation $\varphi = \varphi_o\ e^{i\omega t}$ is assumed, then the differential equation (57) becomes

$$\ldots + a_4 \omega^4 - i a_3 \omega^3 - a_2 \omega^2 + i a_1 \omega + a_o = 0 \quad .. \quad (60)$$

and this equation can only be fulfilled if the separate sums of the real and the imaginary terms are equal to zero:

$$\left.\begin{aligned} \ldots + a_4 \omega^4 - a_2 \omega^2 + a_o &= 0 \\ \ldots + a_3 \omega^4 - a_3 \omega^2 + a_1 &= 0 \end{aligned}\right\} \quad .. \quad (61)$$

The critical frequency ω_k at the stability limit can be determined from eqs. (61), and the stability condition for the coefficients is then obtained from it without using Hurwitz determinants. Examples are given in the following table, and the side on which stability lies is determined from physical considerations for each separate case

If similar calculations are made for damped oscillations $\varphi = \varphi_0\ e^{-\delta + i\omega t}$ (instead of a constant-amplitude vibration), we again obtain a relation between the coefficients, which in this case depends also on the damping factor D of the control process:

$$D = \delta / \sqrt{\delta^2 + \omega_e^2}$$

where δ = decay constant, ω_e = natural angular velocity, and D = damping of one oscillation ($D = 1$: aperiodic, $D = 0$: constant-amplitude vibration).

(e) *Phase Condition.*

The phase condition can be derived from D. G. Reid's proof of the Nyquist criterion. If the transfer function is represented in factored form, then

$$\boldsymbol{F}\ (i\omega) = r_o \prod_n (i\omega - x_{Zn}) / \prod_k (i\omega - x_{Nk})$$

where x_Z and x_N are roots of the numerator and the denominator polynomials of the original transfer function. The locus can then be obtained by multiplication of the individual vectors $(i\omega - x_{Zn}), \ldots, (i\omega - x_{Nk})$. The phase angles are added together in this process. Thus, each bracket factor represents a 90-degree rotation when ω varies from 0 to ∞. The rotation due to a factor in the numerator is in the negative (clockwise) direction only if the root has a positive real part; in the denominator the bracket factors have the reverse effect. If the denominator is stable (roots with negative real part) and has more bracket factors than the numerator, the entire controller element will be stable. No matter what values they may have, the roots of the numerator cannot then affect the negative overall rotation, because of the smaller number of bracket factors in the numerator.

(f) *Number of Eigen-Frequencies.*

The characteristic equation of an n-th order linear homogeneous differential equation is an algebraic equation $a_n x^n + \ldots + a_2 x^2 + a_1 x + a_o = 0$, with the complex roots $x_1, x_2, \ldots, x_n$. The general solution of the differential equation is

$$\varphi = C_1 e^{x_1 t} + C_2 e^{x_2 t} + \ldots$$

If $x_a = -\delta + i\omega$, and $\bar{x}_a = -\delta - i\omega$, and $C_1 = \bar{C}_1$, we have $e^{x_a t} + e^{\bar{x}_a t} = e^{-\delta t}\ 2 \cos \omega t$,

and with $-\delta < 0$ this represents a damped oscillation. For constant-amplitude oscillations, $\delta = 0$. Thus, two complex conjugate solutions correspond to one eigen-frequency. Generally, therefore, an n-th order differential equation cannot have more than $(n/2)$ eigen-frequencies. The real solutions representing aperiodic processes, however, must first of all be determined, and deducted from the total number of solutions n. The determination is achieved graphically, by substituting any arbitrary real values in the characteristic equation, and plotting the result. The zero positions of this curve are then the real solutions. If their number be m, then the total number of (periodic) eigen-frequencies is $(n - m)/2$.

(g) *Nyquist Criterion*

Provided the open-ended loop is stable, the closed loop system will also be stable if the open-loop locus (or transfer function) encloses the end-point of the excitation (or input) vector φ_e, when the curve is followed in the direction of increasing frequencies from $-\infty$ to $+\infty$. In other words, the tip of the excitation vector must be situated to the left of the open-loop locus when the curve is followed in the direction of increasing frequencies.

(h) *Stability Conditions for Loci of Controller and Controlled Unit.*

It is frequently an advantage to subdivide the system into a controller R and a controlled unit S. Generally, the controlled unit behaviour is not variable, but corresponds to a well-determined transfer function $\boldsymbol{F}_S\ (i\omega)$; it is then necessary to adapt the controller R to existing conditions. The excitation quantity is in this case the controlled quantity φ, which is plotted on the positive real axis, and the locus $\mu_R\ (i\omega)$ is constructed for a given controller adjustment. The locus for the controlled unit is its inverse curve, which is the locus of the variation μ_S required at the controlled unit to produce the controlled quantity φ.

Based on the Nyquist stability condition, the following criteria have been derived by A. Leonhard for the μ_R and μ_S loci:—

If the controller and the controlled unit are stable networks, the closed-loop system will also be stable provided (1) that the curves $\mu_R\ (i\omega)$ and $\mu_S\ (i\omega)$ do not intersect, or only do so at the zero-point or at infinity, while the phase of μ_R is in advance of that of μ_S; (2) that the condition $\omega_R > \omega_S$ is fulfilled at every intersection of the two curves for static controller equipment; (3) that the condition $\omega_R < \omega_S$ is fulfilled for astatic controller equipment or for networks with temporarily static character, at the first intersection (smallest ω_R value) in case the controller curve intersects the controlled-unit curve from the right-hand side of the latter.

With these μ-loci, the stability limit, corresponding to sustained oscillations, is reached when the vectors μ_R and μ_S coincide at the same frequency. The conditions in this sub-section are derived from the Nyquist criterion, and only apply to stable open-ended systems. The following stability conditions are not limited by this restriction.

(i) *Stability Criteria for the Transfer Functions of the Reference Datum and Load Disturbance*

By taking the inverse transfer function $1/\boldsymbol{F}_\psi\ (i\omega)$ for the reference datum, the criteria of sub-section (c) can be applied to this inverse function to determine the stability of the closed loop. This is also the case for the inverse transfer function $1/\boldsymbol{F}_\sigma\ (i\omega) = \sigma/\varphi$ for the system with a load disturbance. If $\boldsymbol{F}_\psi\ (i\omega)$ is not known, its inverse function is determined from the open-loop transfer function (see eq. (43)):

$$-1/\boldsymbol{F}_\psi\ (i\omega) = [1/\boldsymbol{F}\ (i\omega)] - 1$$

and $1/\boldsymbol{F}_\psi\ (i\omega)$ is obtained by displacing the imaginary axis by one unit.

ILLUSTRATIVE EXAMPLE

The liquid level φ in a container is maintained constant by means of a direct-acting float-controlled system (see Fig. 20). The "controlled unit," i.e., the container, is then governed by the equation

$$s_1\ \varphi' = -\mu \quad .. \quad .. \quad .. \quad \text{(i)}$$

where $s_1\ \varphi'$ = flow velocity of liquid into the container, μ = valve opening. The "controller" is determined by

$$T_2\ \mu'' + T_1\ \mu' + \mu = r_o\ \varphi \quad .. \quad .. \quad \text{(ii)}$$

where $T_2\ \mu''$ = inertia force, $T_1\ \mu'$ = damping force, μ and $r_o\ \varphi$ = lifting forces.

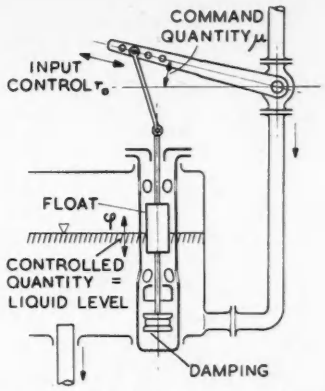


Fig. 20. **Control of liquid level in a container by direct-acting float-controlled system.**

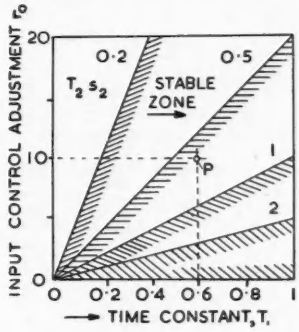


Fig. 21. **The stability zones of the control system shown in Fig. 20, for $s_1 = 10s$.**

Therefore, the closed system is represented by

$$T_2 s_1\ \varphi''' + T_1 s_1\ \varphi'' + s_1\ \varphi' + r_o\ \varphi = 0 \ldots \quad \text{(iii)}$$

The stability limit is determined by referring to eqs. (61) as

$$r_o = T_1 s_1 / T_2 \quad .. \quad .. \quad .. \quad \text{(iv)}$$

This stability limit is indicated in the coefficients diagram of Fig. 21. It shows that the value which can be assigned to the controller element r_o is greater when T_1 increases and T_2 decreases. In this case, therefore, considerable damping (T_1) and a small mass (T_2) for the

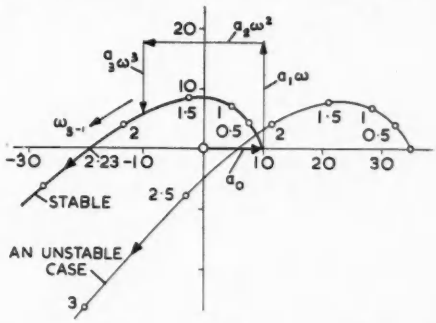


Fig. 22. **Stability criteria of Cremer-Leonhard applied to locus of control system represented by differential equation (iii).**

controller are favourable for stability. The numerical values $s_1 = 10\ s$, $T_1 = 0{\cdot}6\ s$, $T_2 = 0{\cdot}2\ s^2$, $r_o = 0$, for instance, give in Fig. 2 a point P in the stable zone of the curve $T_2 = 0{\cdot}2\ s^2$.

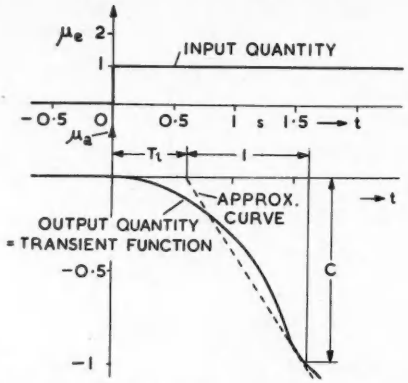


Fig. 23. **The transient function of the open-ended control system.**
(Not drawn to scale.)

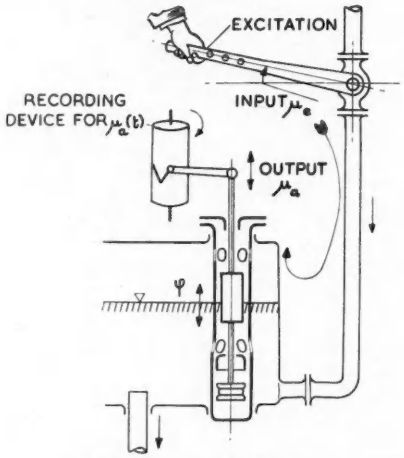


Fig. 24. **The open-ended system.**

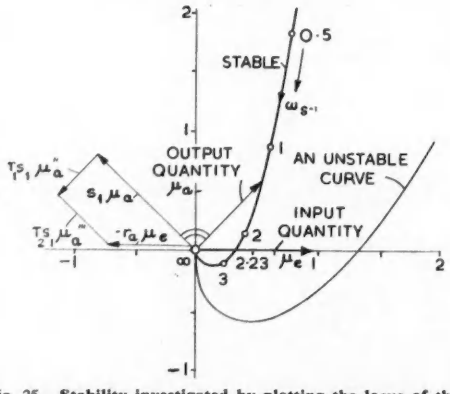


Fig. 25. **Stability investigated by plotting the locus of the open-ended system, according to Nyquist.**

The application of the Hurwitz conditions also shows that the system with these numerical values is stable:

$$\begin{vmatrix} T_1 s_1 & r_o \\ T_2 s_1 & s_1 \end{vmatrix} = T_1 s_1^2 - r_o s_1 T_2$$
$$= 0{\cdot}6 \times 10^2 - 10 \times 10 \times 0{\cdot}2 = 40 > 0.$$

Fig. 22 shows finally the locus for the numerical values chosen in this instance, for assessment by means of the Cremer-Leonhard criteria. The locus passes through the first three quadrants and represents therefore a stable system. An unstable curve (with $r_o = 35$) is also given in the same figure for comparison.

The transient function of the locus considered is approximated in Fig. 23 by a linear rise following a "transmission lag" T_l. Then

$$\varphi_{\ddot{u}}(t) = -c\,(t - T_l)$$

With $\mu_e = 1$ we obtain from eqs. (i) and (ii): $c = r_0/s_1$; and $T_l = T_1$. The integral equation is therefore

$$\varphi(t) + \frac{d}{dt}\,\frac{r_o}{s_1} \int_{t_x=0}^{t_x=t} dt_x\,(t - t_x)\,(t_x - T_1) = 0$$

At the stability limit this gives, with $\varphi(t) = \varphi_o\, e^{i\omega t}$

$$e^{i\omega t} + \frac{d}{dt}\,\frac{r_o}{s_1} \int_{t_x=T_1}^{t_x=t} dt_x\,(t_x - T_1)\,e^{i\omega(t-t_x)} = 0$$

After effecting the integration and inserting the limit values we have

$$(s_1/r_o)\,e^{i\omega t} - (1/i\omega)\,[1 - e^{i\omega(t-T_1)}] = 0.$$

This equation must also be valid for $t \to \infty$, so that

$$(s_1/r_o) + 1/(i\omega)\,e^{-i\omega T_1} = 0$$

and if this relation is resolved into its real and imaginary parts we finally have the result

$$r_o = \pi\, s_1/(2\,T_1) \quad .. \quad .. \quad .. \quad \text{(v)}$$

This does not agree with equation (iv); the approximation of the transient function by means of a straight line is too coarse for this example. The rounded-off portion of the curve, which is chiefly determined by T_2, is not taken account of by this linear approximation.

Furthermore, from eqs. (i) and (ii) we can obtain the equation of the open-ended system (see Fig. 24)

$$T_2 s_1 \mu_a''' + T_1 s_1 \mu_a'' + s_1 \mu'_a = -r_o \mu_e \quad .. \quad \text{(vi)}$$

In the present case, with a sinusoidal oscillation for μ_e and μ_a, the differentiation process is equivalent to a multiplication by ω and a positive 90-degree rotation of the vector. The locus is thus easily determined

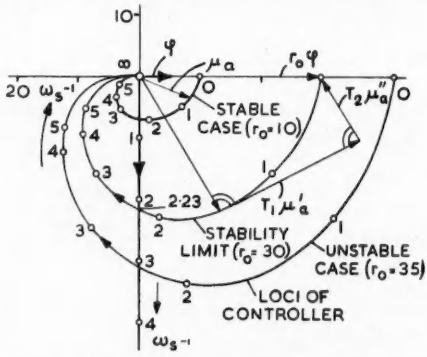


Fig. 26. **Stability investigated by means of the loci for the controller and the controlled unit.**

graphically, and the result, for the numerical values previously assumed, is shown in Fig. 25. The system operates under stable conditions because the tip of the μ_o-vector is situated on the left side of the curve. For comparison, an unstable curve is also shown in Fig. 25.

The loci of the controller and the controller unit used to study the stability of the system are given in Fig. 26. The controller locus is obtained from eq. (ii). In plotting the locus of the controlled unit the input and output quantities must be interchanged, since the input of the controlled unit is the controller output, and conversely. The controller-unit locus is obtained from eq. (i). Stability exists with the numerical values chosen for this example. For comparison, a second locus of the controller is plotted, in which the value of r_o has been increased to such an extent that the system operates right on the stability limit. A third curve is also shown which corresponds to unstable conditions.

U. S. A.

Plastic "Electrets" are nearing Industrial Application

By T. A. DICKINSON. (From *Electrical Manufacturing*, Vol. 42, No. 2, August, 1948, pages 101-103, 8 illustrations).

IN his "Experimental Researches in Electricity," published in 1839, Michael Faraday suggested the possibility of a "dielectric body which retains an electric moment after the externally applied electric field has been reduced to zero." Later in the same century, Oliver Heaviside coined the word "electret" to describe such a dielectric body in his "Electrical Papers." Yet it was almost 90 years after Faraday's suggestion that the first electrets were made. This was achieved by Mototaro Eguchi, of Tokyo, who explained his successful efforts in terms of the following theory:

"When an electric field is applied to a melted substance, the molecules or clusters of molecules (which, supposedly, contain electric doublets) orient themselves with their axes in the direction of the electric field, so that, when the substance solidifies, the molecules will retain their orientation, causing the substance to retain a permanent electric polarisation." (Fig. 1).

Electrets can be fabricated by means of comparatively simple methods, as indicated in Figs. 2 and 3. Generally speaking, the materials from which electrets can be made must have the following qualities:

(1) A complex molecular structure with enough double bonds to permit re-orientation of atoms without disintegration in the electric field.
(2) Thermo-hardening or thermo-plastic properties which will permit the material to solidify in the electric field.

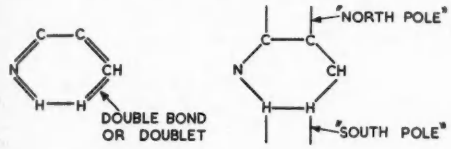


Fig. 1 (left). **Hypothetical representation of a non-polarised dielectric molecule.** (Right) **Representation of a polarised dielectric molecule of the type which theoretically exists in electrets.**

In the laboratory, electrets have been fabricated from wax-type compounds for a number of years without noteworthy commercial success. However, processes have recently been developed for the manufacture of electrets from plastics, and there are indications that such products will soon achieve a status of industrial importance. The manufacture of electrets from ceramics has also been reported. While this material would find applications where high-temperature resistance is required, electrets from resinous or resin-bonded materials have the following advantages:

(1) They can be fabricated into finished products with maximum economy.
(2) They can be produced in various colours, and also glass-clear.
(3) They can be compounded with a variety of non-plastic materials, e.g., glass and asbestos fibres, in order to impart to them a higher mechanical strength or other desirable properties.
(4) They can be machined or shaped without danger of breakage or damage after they have been fabricated by moulding or casting methods and electrification.

From the manufacturer's viewpoint, thermoplastic resins should be the most desirable electret materials. However, engineering requirements will probably involve the extensive use of thermosetting resins.

Particularly good results have been attained in the fabrication of electrets from polyester resins (which are made by combining thermoplastic and thermosetting materials) due to the fact that these resins have an ideal chemical structure and will often react like thermoplastics until they are fully thermo-hardened.

The charging current required to electrify various thermosetting and thermoplastic resin compounds is

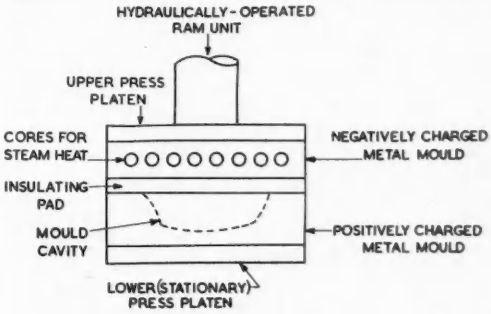


Fig. 2. **Schematic set-up for compression moulding of electrets from thermosetting plastics.**

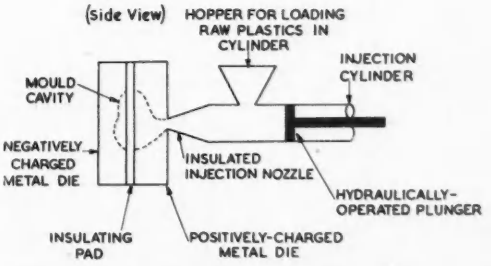


Fig. 3. **Schematic set-up for injection moulding of electrets from thermoplastics or meltable dielectric materials.**

frequently difficult to determine because of the large number of variables that may be encountered. For example, if a resin is catalysed with an acid hardener, the electrolytic properties of the fluid compound may be far superior to the corresponding properties in an identical compound catalysed with another agent.

However, it has been found that an e.m.f. of 4000 to 12000 volts can meet the majority of production requirements. High current intensities are not essential in most cases, because the exothermal reactivity of plastics necessitates minimum heating effects within the electric field. The usual range is 2 to 10×10^{-11} amperes.

The electrification and moulding of an electret are accomplished simultaneously with two-piece metal moulds or dies, which are separately charged by a d.c. power source. Insulation between moulds prevents short-circuiting, and when extraneous heat is required (e.g., to delay the cooling of thermoplastic, or to speed the curing of thermosetting materials) it is desirable to steam-heat one of the mould units. Only small pressure is exerted by the moulds, because high pressure can seriously impair the mobility of atoms which must be reorientated.

Physically, electrets may be compared with pyroelectric crystals, except for the fact that the latter must be heated in order to produce even temporary signs of electrification, whereas the former may be stored for several years without apparent diminution of the original charge.

In specimens $\frac{1}{2}$ in. square and $\frac{1}{8}$ in. thick, plastic electrets have an average charge equivalent to one coulomb per second in tests lasting approximately 5 minutes each. Longer tests indicate progressively diminishing charges; yet, in a series of five-minute tests, individual electrets have shown no appreciable diminution of electrification for periods of more than a year. Further, it has been found that renewed charge measurements can be obtained after a short period of rest, even when the electrification of an electret has apparently been exhausted by prolonged testing.

Even the largest electrets individually provide very feeble electrostatic fields, yet a group of small electrets can be assembled so that their combined fields will duplicate a ferromagnetic field. As electromagnets, electret assemblies may attract either ferrous or nonferrous materials.

Because the electrification of electrets will not deteriorate for a long period of time, it is believed that plastic electrets will be particularly valuable in the manufacture of inexpensive, yet highly efficient, microphones and loudspeakers. The large number of other potential applications ranges from parts for optical instruments to a new type of dry battery in which the electrostatic charges are said to have been converted into current.

SWITZERLAND

Output Control of Piston Compressors

By O. WALTI. (From *Technische Rundschau Sulzer*, No. 2, 1949, pp. 13-24, 12 illustrations.)

SOME industries require the amount of air or gas compressed in unit time to be variable and closely controlled to suit requirements. Variations often extend over a wide range; the control must be stable and operation should remain efficient. The amount of gas compressed depends mainly on cylinder dimensions and speed, the state of the gas before compression and the volumetric efficiency of the machine being only secondary considerations.

1. *Speed Regulation.*

Where engine or motor speed can be varied, speed regulation constitutes the most efficient means of control. This is one of the reasons for the popularity of direct steam-driven compressors for large plants. The steam engine operates with high efficiency over a large range of speeds and the throttling losses in the compressor are also reduced with reduction of speed. Efficient speed regulation of electric motors, however, requires an expensive plant, and usually some electrical losses are accepted if plant costs can be kept down.

2. *Regulation by Disconnection of a Cylinder.*

Where the first stage of a compressor comprises several cylinders or half-cylinders connected in parallel, one or more of these can be disconnected from the supply so that the compressed volume is reduced. However, any volume changes in the first compressor stage produce changes of pressure in the higher stages and may lead to excessive heating of the compressed gases.

3. *By-pass Valves.*

With small compressors, part of the compressed gases can be made to flow back through a by-pass valve into the suction pipe. This arrangement works uneconomically, but is very easily added to the compressor plant besides being inexpensive. With multistage compressors, by-pass valves are usually arranged in the first stage only, provided the compressed gases in the higher stages do not become unduly heated.

4. *Regulation by Throttling.*

A throttle arranged in the suction pipe creates a partial vacuum and thus diminishes the amount of gas sucked into the cylinder. This regulation is again uneconomical, since the power required for compression is increased. Pressure and temperature changes in the higher stages have to be watched. This arrangement cannot be used with gases forming explosive mixtures with air which might penetrate into the suction pipe.

5. *Intermittent Working.*

If the compressed gas is collected in a large receiver, the amount of gas compressed can be reduced by intermittently stopping the compressor or by idling. A pressure relay stops the compressor when the pressure in the receiver reaches a certain high limit and switches it on again when the pressure has dropped to a certain low limit. The larger the receiver and the wider the permissible pressure range, the more advantageous will be this arrangement. Its disadvantages are the irregular sudden electric power requirements, the consequent electric losses, and the irregular intermittent noise.

6. *Additional Clearance Spaces.*

The compressed gas remaining in the clearance space of the cylinder expands during the suction stroke, and the inlet valve only begins to admit fresh air or gas after the gases in the cylinder have been expanded to suction conditions. The larger the clearance space as compared with the swept volume, the larger will be the space occupied by the expanded gas and the smaller the amount of gas freshly admitted. The amount of gas compressed can thus be regulated very economically by the addition of clearance space. The simplest

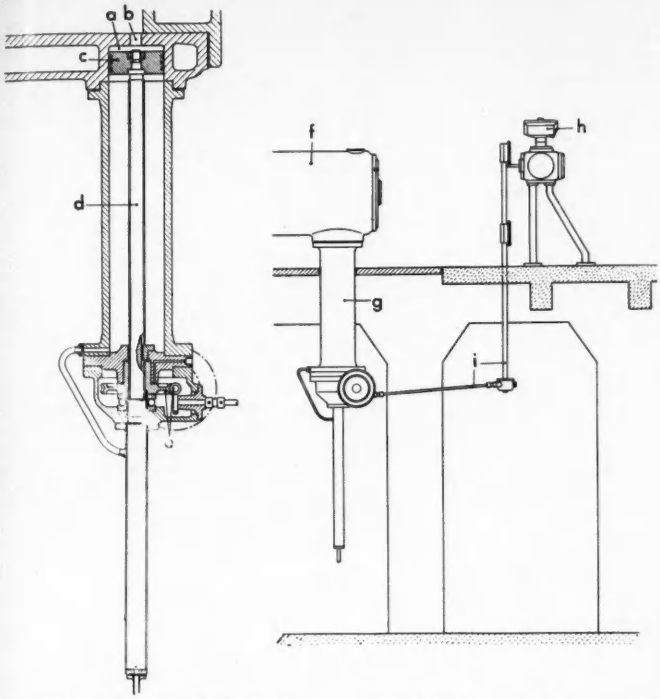


Fig. 1. **Load control of high-pressure gas compressor by means of infinitely variable clearance volume.**

a = Additional clearance volume,
b = connection with cylinder clearance space,
c = adjustable piston,
d = threaded piston rod,
e = worm gear with electric motor drive,
f = compressor cylinder,
g = casing for additional clearance space,
h = position indicator,
i = transmission linkage.

arrangement is the use of steel bottles opened or closed by hand as required; a more usual arrangement is that of two or more additional enclosed pockets connected to the cylinder clearance space by automatically controlled valves, so that one or more pockets can be added alternately or simultaneously. However, regulation is only possible in fairly large steps. Clearance spaces can be added to one or several stages of a multi-stage compressor.

7. *Infinitely Variable Clearance Volume.*

If the additional clearance space consists of a cylinder with adjustable piston position inside the cylinder, the clearance-volume can be adjusted in infinitely small steps. This solution, however, presents certain constructional difficulties and is not cheap. In spite of its economic advantages, this arrangement is, therefore, seldom used. (Fig. 1).

8. *Spring-Controlled Inlet Valve.*

If the inlet valve is kept open by spring pressure during part of the compression stroke, no compression can take place as long as the inlet valve is open. The amount of air compressed is thus reduced. Fig. 2 shows the Sulzer design of a spring-controlled inlet valve. The movable dished plate *b* is rigidly connected with valve disc *e* and loaded by spring *f* the pressure of which can be manually adjusted by handwheel *h* and spindle *g*. During suction, the gases flow freely

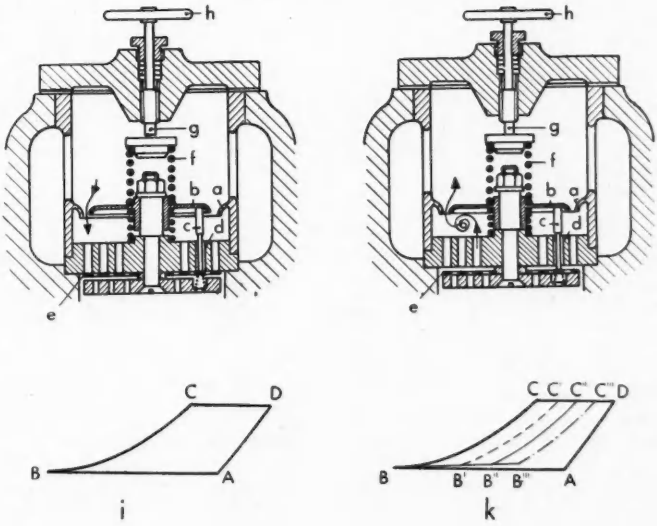


Fig. 2. **Schematic arrangement of compressor inlet valve with Sulzer throttling control.**

a = Stationary part of throttle,
b = dished plate (movable throttling plate),
c = pins connecting valve disc and dished plate,
d = valve seating,
e = valve disc,
f = load control spring,
g = spindle,
h = handwheel (with position indicator if required),
i = indicator diagram for full load,
k = indicator diagrams for partial loads.
A = start of suction period,
B = start of compression stroke,
C = end of compression,
D = start of expansion of clearance-volume gases.

round plate *b*, but during compression the valve disc *e* is first kept open by spring pressure *f*. Only when the spring pressure is exceeded by the fluid pressure built up underneath plate *b* by gases flowing back into the suction pipe will the valve finally close. The fluid pressure depends on the speed of the gases, and plate *b* is specially shaped to offer maximum resistance to gases flowing back. The indicator diagram ABCD (Fig. 2) shows full-load operation; the diagrams ABB′C′D, etc., show operation at reduced loads according to different spring adjustments. Normally, inlet valves to all compressor stages are spring-controlled and the spring pressures are automatically adjusted by common hydraulic remote control.

The arrangement works very efficiently and, next to speed regulation, is the most economical load control. Since the piston speed is highest at about midstroke, it would be expected that if spring pressure were so adjusted as to keep the valve open beyond midstroke, the fluid pressure would drop again and the valve not close at all. Actually, however, secondary influences may delay closure to 70 per cent of the compression stroke and extend the control range down to about 30 per cent of full load. Below this range, the control becomes unstable, the valve sometimes being held open during the whole of the compression stroke and the compressor running empty. A hydraulic remote-control device can, however, be arranged so that even the intermittent working range below 30 per cent can be positively controlled.

Fig. 3 shows the inlet valve of Fig. 2 with added hydraulic control of the spring adjustment. At standstill and during starting, spring *e* presses piston *c* into its lowest position so that valve spring *a* exerts the maximum pressure and the valve is constantly kept open. The compressor thus starts on no-load. As the lubricating oil pump starts to supply high-pressure oil, this is led into space *f* and begins to lift piston *c*, thus reducing spring pressure *a* and freeing the valve. At full oil pressure, the piston is lifted so far that the valve operates under normal full-load conditions. Fig. 4 shows a servo-valve for the control of oil pressure. Handwheel *a* controls the spring pressure on the valve piston *b*. If the piston is to stay in the equilibrium

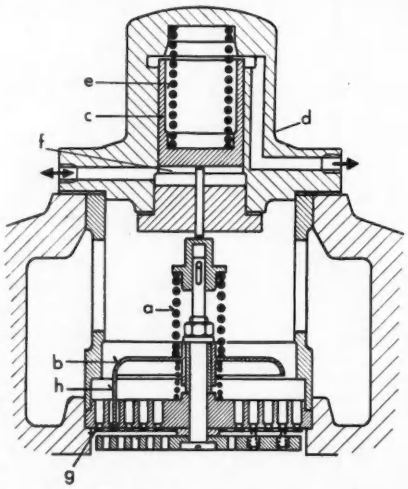


Fig. 3. **Hydraulically controlled compressor inlet valve with Sulzer throttling control.**

a = Load control spring of dished plate, *b* = dished plate, *c* = servo-piston, *d* = valve cover, *e* = piston spring, *f* = space filled with control oil, *g* = valve disc, *h* = connection between dished plate and valve disc.

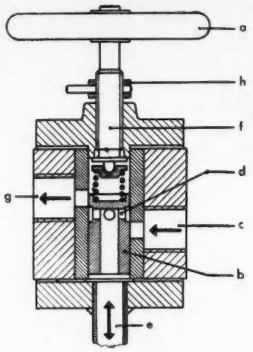


Fig. 4. **Servo-valve for hydraulic remote control of compressor inlet valve.**

a = Handwheel,
b = servo-piston,
c = oil inlet,
d = oil holes in piston,
e = pipe connection to inlet valves,
f = spindle,
g = oil outlet to sump,
h = lock nut.

position as shown, the oil pressure in *e* must balance the spring pressure. If the piston moves out of its equilibrium position, the oil pressure in *e* is either increased or reduced until balance is restored. The manual control can be replaced by an automatic control operated by pressure variations in the H.P. receiver or by temperature changes. Fig. 5 shows Sulzer remote control of inlet valve automatically actuated by the pressure of compressed gases.

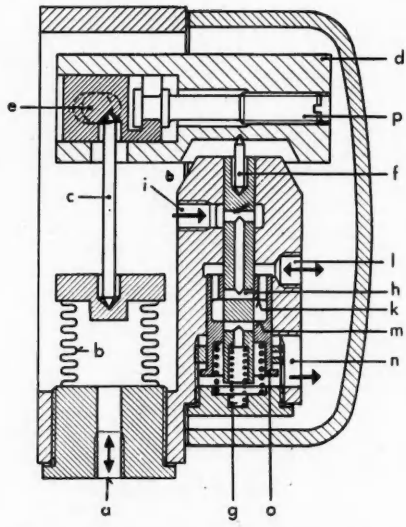


Fig. 5. **Automatic remote control of inlet valve operated by working pressure of compressed gases.**

a = Connection to H.P. receiver, *b* = high-pressure bellows, *c* = spindle transmitting pressure variations, *d* = heavy fulcrum lever *e* = adjustable fulcrum of lever *d*, *f* = servo-spindle, *g* = supporting spring for servo-piston, *h* = servo-piston, *i* = H.P. oil inlet, *k* = upper control edge of piston, *l* = connection to inlet valves, *m* = lower control edge, *n* = oil outlet, *o* = damping control piston, *p* = adjustment of fulcrum position and lever arm ratio.

The constructional arrangement is very simple. The controlled inlet valve does not take up much more space than a normal valve and the remote control can be arranged as required, with only oil pipes leading to the inlet valves. The arrangement is inexpensive, and controlled inlet valves can, therefore, be used for each stage of the compressor. The remote control details are standard parts, identical with those used for different types of machines and engines.

WORKSHOP TECHNOLOGY

New Production Methods for Transformer Sheets

By Y. S. KRONGAUZ and N. I. NAZAREVSKY. (From *Vestnik Elektropromyshlennosti, Russia*, No. 11, 1948, pp. 24-28, 9 illustrations.

THE Kuybyshev Transformer Factory in Moscow has developed and introduced new methods of production for power transformer sheets, entailing complete reorganisation of the process and leading to a very considerable saving in time and increase of output. The main feature of this reorganisation was the complete mechanisation of production and transport of the sheets. This affected the layout of the shop, positioning of machinery and design of machine tools, etc. The new technological process resulted in the following savings :

(1) Combining of two working operations in one (stamping of sheets and holes).
(2) Dispensing with manual stacking of sheets, after certain operations.
(3) Fully automatic grinding of sheets.
(4) Conveyor belt transport of sheets between consecutive operations.
(5) Increase in the number of sheets handled simultaneously to 4-6, by equipping the presses with numbers of parallel cutters.

The production was concentrated in four independent lines, each being laid out to permit a straight-through flow from the point of entry of the raw material to the issue of the completed transformer sheets. To ensure flexibility of supply to the four production lines, a distribution table is installed near the machines which cover the sheets with paper. The table is pneumatically operated to supply packets of sheets weighing 1½ tons to these papering machines.

The first two production lines are for sheets serving transformers up to 560 kVA, the steel passing through the following processes :

(1) *Papering of the sheets* in the papering machine, from which they are transported to drying chambers at a temperature of 105° C, and then cooled to 30° C by means of fans.
The sheets are then automatically stacked on a conveyor, which transports them periodically to a 60-ton press when the motor driving the belt is started manually. The conveyor delivers the stacks on to a turntable, which is then turned by 90 degrees and from which the operator withdraws the individual sheets for the second operation.
(2) *Cutting of sheets.* This is done by the press simultaneously in one operation by means of several pairs of cutters and under the supervision of one operator. On the average, one sheet is cut into four blanks ; thus, a shift worker at the press cuts 8,800 blanks per shift, instead of 1,500 cut previously on a guillotine.
The cut blanks are removed from the bedplate and automatically sorted into sizes. The operator only has to place the sheet on the platen and press a foot-pedal to start the cycle of operation.
(3) *Cutting of sheets to size and stamping of holes.*
Whereas, previously, these two operations were carried out separately, now the whole process is carried out by one compound die. The output of an operator per shift has consequently risen from 2,300 to 10,000 sheets.

The press is equipped with compound dies, mechanical means for removing sheets and an auxiliary conveyor transporting the sheets to the main conveyor belt. For sheets of a width exceeding 100 mm (3¾ in.), the press is equipped with electromagnetic supports to prevent them from sagging. The feed to the electromagnets is cut off automatically to permit the sheets to fall on to the auxiliary conveyor. Superior design and material of the dies has increased their life considerably ; whereas the average number of cuts for dies used to be 25,000 to 30,000, it is now of the order of 200,000.

To ensure a continuous supply of raw material for the operators, a turntable with two shelves is allotted to each press. As soon as one shelf is emptied, the operator revolves the table by 180 degrees and the empty shelf is immediately replenished while the operator continues with the second shelf. The sheets are transported to the next operation—the grinding of burrs on a three-belt conveyor, each belt feeding a separate machine handling three sizes of sheets.

(4) *Grinding :* While this previously required hand feeding, now the feed is carried out automatically and the grinding is done simultaneously in three passes. The width of the grinding machine is 700 mm, the width of the three belt conveyors being $3 \times 220 = 660$ mm (26 in).

The manufacture of sheets is now carried out in four principal and eight auxiliary operations, as against the 25 required previously. The distance of travel for the sheets is reduced from 120 m to 90 m (300 ft) and the duration of manufacture is shortened by 1·8.

The third production line caters for transformers of 7,500 to 60,000 kVA rating. The dimensions of transformer sheets for these ratings are close to the dimensions of the sheets as received, and the cutting consists primarily of trimming the edges, which is carried out on a 2-ton guillotine.

The two rows of holes in the transformer core sheets are stamped in one operation on a 65-ton press equipped with a universal male die holder, bed die holder and stops, which are removed during the operation. The stamped core sheets fall on to a multi-belt auxiliary conveyor leading to the main conveyor which transports the sheets to the grinding machine. The press is so designed that it can be rapidly set up for different requirements. The number, position and distance between dies can be set easily and accurately without measuring instruments, by inserting the cutting dies into the seats provided for them, and the same applies to the bedding dies.

The setting-up of the press for a new design of core sheets takes a maximum of 1·75 to 2·0 hours, whereas previously the time taken, requiring more highly skilled labour, was 4·0 to 4·5 hours. This reduction is most important, as, for large transformers, sheets are manufactured in smaller batches.

The method of grinding the sheets has been radically improved and both sides are now ground in one operation, thus dispensing with the necessity of

turning the sheets over between the two grinding operations previously required. The grinders have been designed in the factory and include two grinding wheel assemblies, one below and the second above the sheet. The feed is again fully automatic, this also being so for the drawing of the sheets through the two sets of grinding wheels and stacking on shelves ready for the transport to the last operation—the varnishing of sheets. One single operator now serves the two grinders and two conveyors of the third and fourth lines of production. The productive capacity of the new arrangement for grinding has thus been increased threefold.

The varnishing process is still carried out as before with the aid of rollers.

This production line now requires 6 main and 16 auxiliary operations as against 46 originally. The length of travel through the shop is reduced from 255 m to 170 m (56 ft) and the time shortened by 1·8.

The fourth production line deals with sheets for transformers of 750 to 5,600 kVA ratings. This line has its own machine for covering the sheets with paper. The cutting-up of large sheets and cutting to dimension has not been altered, but improvements have been achieved through the substitution of the crane by conveyor belts. The stamping of the holes is carried out on two 30-ton presses, from which the sheets are transported on conveyor belts to the grinding machine, which is fully automatic, as in the other three lines. The length of travel of the sheets on this line has been reduced from 165 m to 105 m (35 ft) and the time for the complete cycle of operations has been shortened by 1·7.

As a consequence of the improvements described in this article, the production of the shops, per head, has been raised from 2,007 kVA to 3,960 kVA, or 97 per cent; at the same time, the quality of manufacture has been considerably improved.

New Designs of Milling Cutters for High-Speed Machining

By I. G. TURCHANINOV. (From *Stanki i Instrument, Russia*, No. 12, 1948, pp. 7-9, 4 illustrations).

HIGH-SPEED milling requires a high degree of accuracy in the milling cutters, particularly as regards the concentricity of cutting edges, the permissible tolerance being 0·02 to 0·03 mm. Honing of cutting edges becomes a necessity, as it considerably lengthens the useful life of the cutter.

These requirements can be satisfied either by grinding and honing of the assembled milling cutter or by accurate adjustment of the knives after they have previously been individually ground and honed. The latter method has several obvious advantages and has, therefore, been selected and developed; in addition suitable milling cutters have been designed to keep within the specified tolerance of 0·02-0·03 mm (0·0008-0·0012 in).

(1) END MILL WITH INDEPENDENT ADJUSTMENT OF KNIVES (Fig. 1).

The knives (1) are inserted into slots (7) of the end mill; radial adjustment is effected by means of the wedges (5) which are enabled by screws (6) to slide along the inclined surface of the slot. Axial movement of these screws is prevented by the ring (9), which is provided with slots, along which radial movement of the screws can be effected.

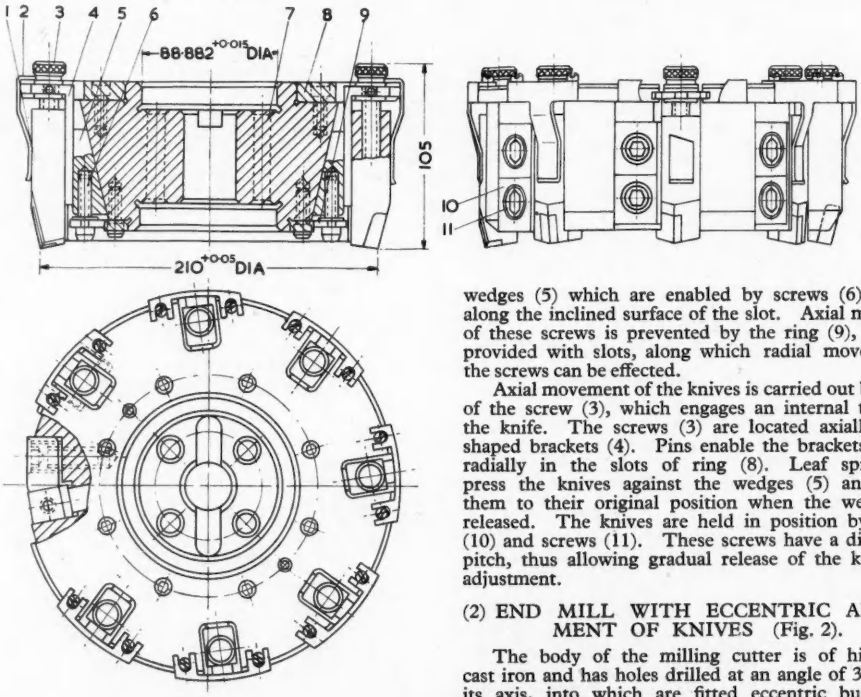


Fig. 1

Axial movement of the knives is carried out by means of the screw (3), which engages an internal thread in the knife. The screws (3) are located axially by L-shaped brackets (4). Pins enable the brackets to slide radially in the slots of ring (8). Leaf springs (2) press the knives against the wedges (5) and return them to their original position when the wedges are released. The knives are held in position by wedges (10) and screws (11). These screws have a differential pitch, thus allowing gradual release of the knives for adjustment.

(2) END MILL WITH ECCENTRIC ADJUSTMENT OF KNIVES (Fig. 2).

The body of the milling cutter is of high-grade cast iron and has holes drilled at an angle of 35 deg. to its axis, into which are fitted eccentric bushes (3). The internal surface of the bushes is eccentric with

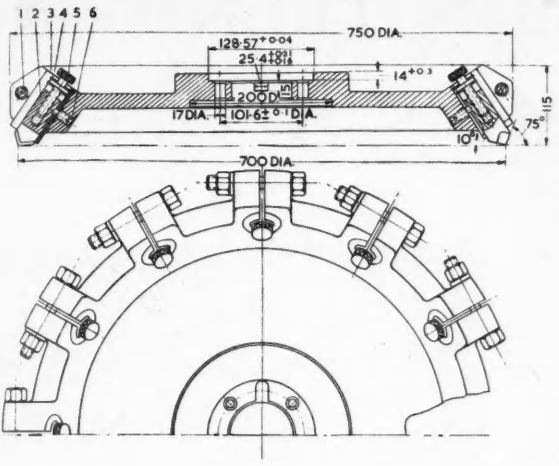


Fig. 2

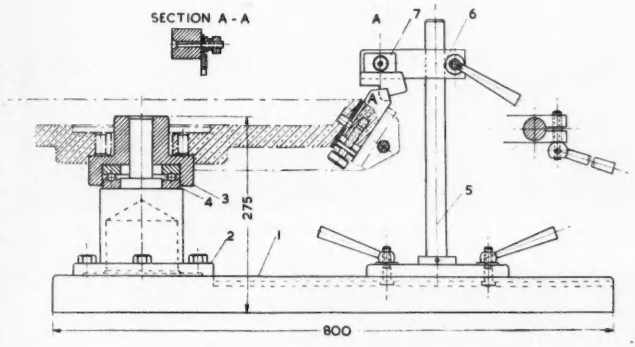


Fig. 3

respect to the external surface, the eccentricity being 5 mm. Two slots in the bushes house springs (4), which, in turn, locate the screws (5) for the axial adjustment of the knives. Locking screws (6) prevent the knives from turning. The eccentric bush is provided with slots for the insertion of a special key, which can turn the bush and thus move the knife in a radial direction.

(3). The adjustment of the knives is carried out in the jig shown in Figs. 3 and 4. The table (1) is fitted with a support (2) on which can be placed bush (3) and thrust bearing (4). The end mill fits over the bush and can be rotated.

A template (7), used for preliminary adjustment of the knives, sits on the cross-piece (6), which can slide along the support (5). For the final adjustment (Fig. 4), an assembly with two indicating gauges is placed on the support (5). This enables the knives to be checked simultaneously for accurate adjustment of the cutting edge and top surface.

(4) GRINDING AND HONING OF KNIVES.

Grinding is done on an ordinary grinder having a vice capable of turning in three planes, and is carried out in two operations, firstly, for the whole of the cutting and rear edges, and secondly, only for those sections of the edge which have to be honed.

(5) ABRASIVES.

Preliminary grinding is carried out on carborundum wheels of 150 mm diameter having a grain size of 46. For the final grinding, the grain size used is 60 to 80.

Speed of grinding for ooth operations is 25 m/sec. The depth of material removed is 0·01 mm (0·0004 in) for the first operation and 0·005 mm (0·002 in) for the second.

The honing is done on a cast iron disc using a paste of boron carbide.

(6) TESTING OF MILLING CUTTERS.

Tests were carried out on a vertical milling machine with a 40-kW driving motor, the results being as follows :

(a) the accuracy of adjustment was found to be satisfactory.

(b) time required for the adjustment of each knife was 10 minutes.

(c) with a cutting speed of 263 m/min (860 fpm), a feed of 0·145 mm (0·006 in) per knife and a cutting depth of 15 mm ($\frac{9}{32}$ in) the assembly retained the dimensions to which it was set.

(d) The milling cutter with eccentric adjustment, which was intended for finishing cuts, showed similar test results, and with a cutting speed of 200 m/min, a feed of 0·08 mm per knife and a cutting depth of 3 to 4 mm, it retained its dimensions satisfactorily.

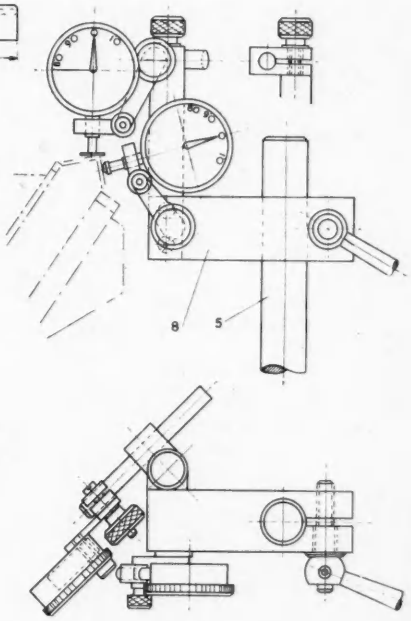


Fig. 4.

DESIGN TRENDS AND TH

OF MACHINE TOOLS

Fig. 38. **Smart & Brown lathe, Model H.** (*Design: Norman Rissen*).

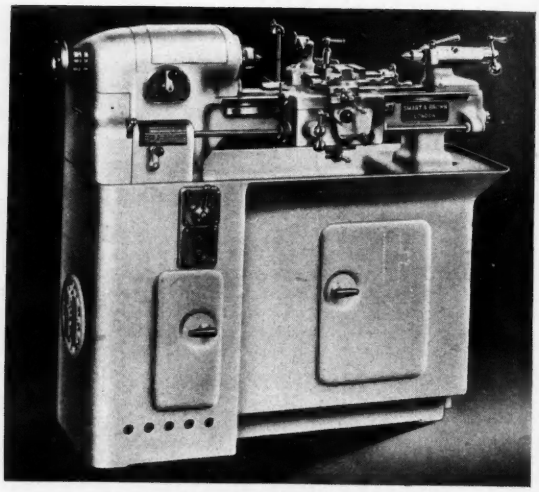


Fig. 39. **Smart & Brown lathe, Model M.**

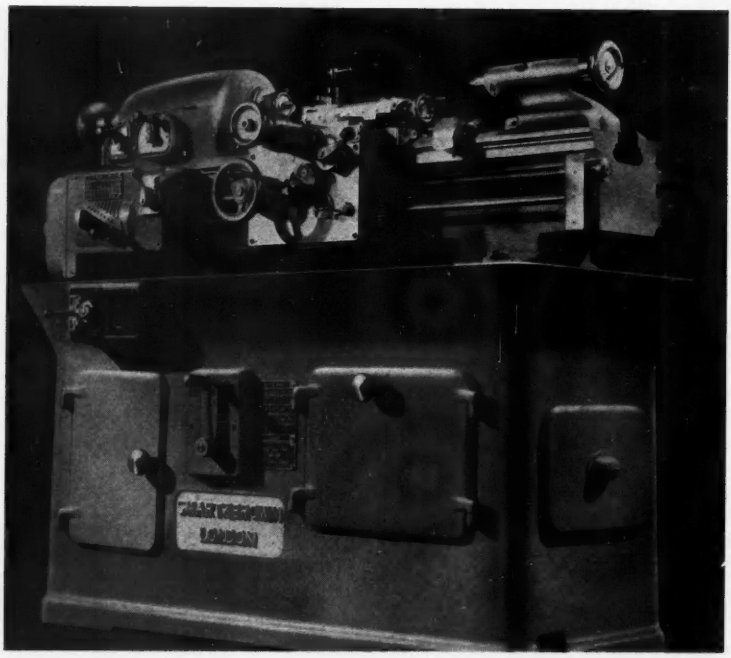


Fig. 40. **Smart & Brown, Model A, sliding, surfacing and screw cutting lathe.** (*Courtesy Aluminium Development Association*).

THE STYLE

By TIBOR HAAS, A.M.I.Mech.E., A.F.R.Ae.S.

LATHES—PART III.

The firm Smart & Brown brought out its first post-war lathe about two years ago. It was designed in co-operation with the industrial designer Norman Rissen. In this design (Fig. 38) considerable saving was effected by replacing three separate castings of the pre-war model by one, and in this process of integration the appearance of the lathe was also enhanced.

The Smart & Brown lathe, Model M, is shown in Fig. 39. It has a centrally located leadscrew, for which advantages of centre line thrust and protection from damage and swarf abrasion are claimed. Against this, the drawback of inaccessibility of the leadscrew has to be taken into account. This machine was fully described from the functional viewpoint in the July, 1948, issue of this journal and, therefore, only its good points from the industrial design angle need be mentioned here. These are "Easy Clean" trays, a recessed base for toe room, well-rounded contours of castings, clean lines generally, and doors of ample size in the base with built-in racks at the back of the doors for accessories.

A still more recent development is the Smart & Brown lathe, Model A, Fig. 40. It makes extensive use of light alloys and is a robust yet pleasing design. Much can be done towards obtaining clean lines by observing even such minor points of appearance as the lining-up of the upper edges of doors in the base.

Kerry's 5-in lathe on a welded steel column base, with a drawer between the columns, is another pleasing clean-lined design, Fig. 41. In Part I of this article, under the heading "Mechanical Design," reference was made to the recent application of cylindrical slides.

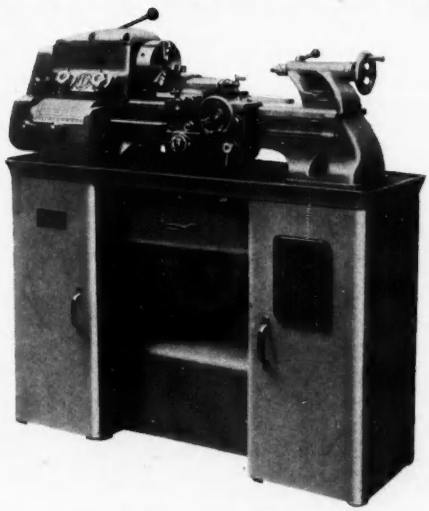


Fig. 41. **Kerry 5-in precision lathe.**

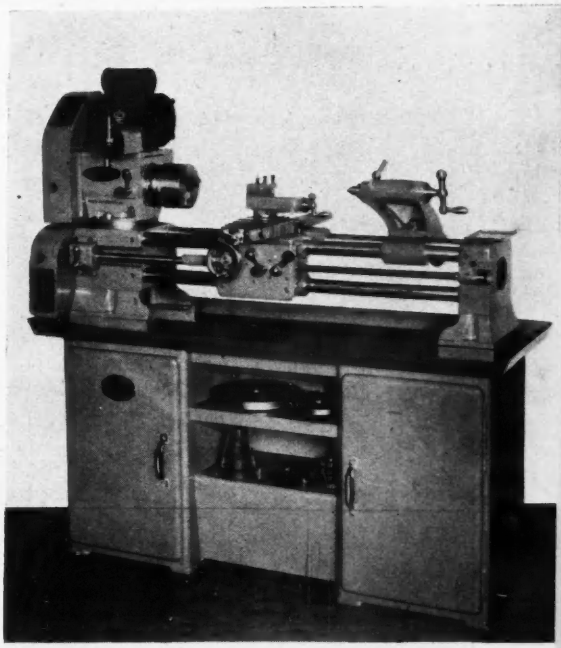


Fig. 42. **The Barker 5-in lathe with swivelling headstock.**

In the 5-in lathe recently introduced by the Barker Machine Tool and Equipment Ltd., of London, Fig. 42, use is made of this principle. The lathe bed thus consists of three 1½-in diameter carbon steel precision-ground bars mounted in a right-angle triangular formation. These bars are easily replaceable; they are assembled into the castings and locked in position by grub-screws.

The saving in material and fitting time in the course of manufacture or maintenance is remarkable. Tests show that the constructional rigidity of the lathe is highly satisfactory.

Another feature worth noting is the swivelling head. The whole headstock can swivel on a spigot 30 degrees each way, which enables the cutting of tapered threads or tapered bores without the use of a taper turning attachment.

Fig. 43 shows the Fortis lathe mounted on a cast iron pedestal base stand. This 6-in. centre lathe, built to Schlesinger limits, is suitable for both toolroom and production work. The tool cabinet and adjustable motor bracket are contained in the left-hand pedestal.* Its somewhat larger American counterpart, the South Bend 9-in lathe, is shown in Fig. 45 for two reasons. Firstly, it illustrates well the identity of form dictated by functional requirements as referred to above and often termed the "form follows function" principle. Secondly, because the latter principle requires qualification as to the degree of completeness of the design procedure,[13] these two designs afford an interesting

*A new model of this lathe with a fabricated steel cabinet has been shown for the first time at the recent *Engineering and Marine Exhibition*. This, in our opinion, shows a marked improvement in appearance, and we have, therefore, included it in this article. The new model is illustrated in Fig. 44.—*Ed., E.D.*

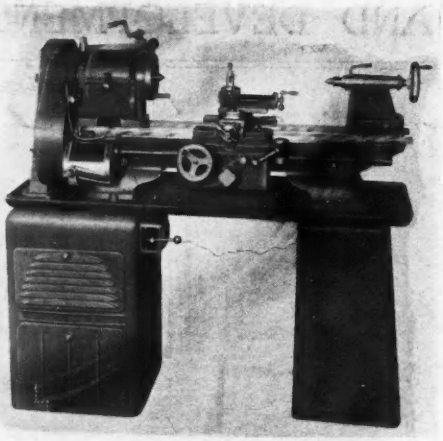


Fig. 43. **Fortis 6-in lathe, Model E/B.**

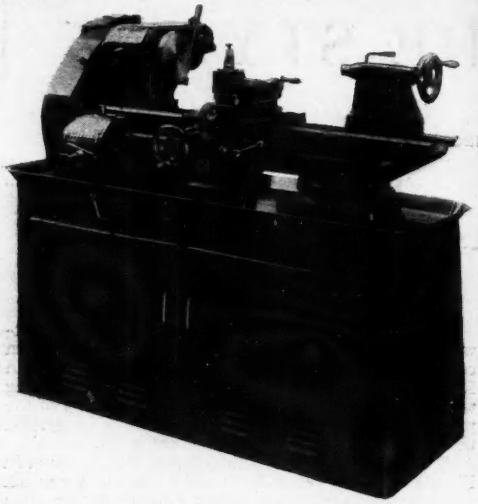


Fig. 44. **Fortis 6-in lathe, Model S/C.**

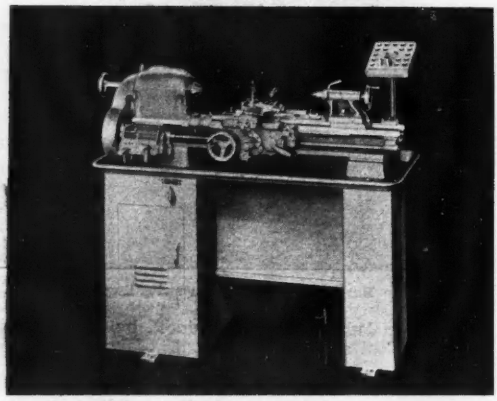


Fig. 45. **South Bend, 9-in lathe.**

comparison. Form follows function, and form somewhat modified or presented in a different material, or by a different process, may still follow function and impart increased aesthetic appeal. In Fig. 45, the latter is obtained by a welded steel column base with an interconnecting rib, topped by the chip pan, forming a harmonious unit. The collet rack with a recess for holding a spanner wrench is a highly desirable feature.

The British-Milnes 13 in. swing lathe is a general purpose precision machine (Fig. 46) and is a post-war development incorporating, *inter alia*, reverse clutches for ease of cutting odd pitch screw threads, feed reverse built into the headstock, dual clutch control lever and Norton-type feed box. An interesting feature of the lathe is that the saddle slides along a vee and a flat, the vee being at the front, but having unequal angles; the cutting thrust is taken on the steep side of the vee. It will be noted that in this case the ratio of the areas of the vee is the reverse of that mentioned in Part I as giving minimum machining inaccuracies.[2] It is a pity that greater thought was not given to the legs of this machine.

The Victoria 8-in heavy duty high-speed precision lathe is a recent design suitable for both production and tool-room use. As can be seen from Fig. 47 it has a number of noteworthy features. The range of nine speeds given by the gearbox is doubled by back-gears in the headstock; thus, 18 spindle speeds extend from 23 to 1300 rpm. The two ranges complete a geometric progression but do not overlap. The gearbox is fitted with a pre-selector system (see Part I) whereby any speed may be selected whilst the machine is running or stationary, by turning a conveniently situated dial to show the appropriate reading. When required, the chosen speed is engaged by operating the adjacent engaging lever. There is thus no chart to be read and no inching through intermediate speeds as in the case of cam change mechanisms. The Norton box with oil bath lubrication is chip-proof and splash-proof. English to metric change-over is effected by a single lever. The electrical contactors, overloads, etc., are housed in the end pedestal; a pilot lamp shows when the primary circuit is energized. The Victoria lathe is a good example of a British lathe of rugged construction with pleasing lines.

Yet another noteworthy British machine tool is the 13-in Dean, Smith and Grace lathe, Fig. 48. The multichange gearbox gives 41 different sliding feeds and 41 different surfacing feeds. It is neat and sturdy. The change gear cover is of light alloy. The bed is made from a semi-steel mixture having a Brinell hardness of approximately 200. A protruding lip on the front bed protects the leadscrew from falling cuttings. The saddle is fitted with guard strips for the Vee-slides.

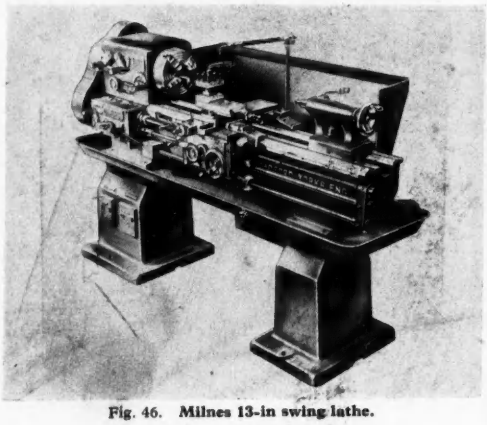


Fig. 46. **Milnes 13-in swing lathe.**

Space does not allow of illustrating more of the great number of British lathes, most of which were shown last year at Olympia, London, and are recorded in literature.[10, 12, 14] A good representative example of these is the Holbrook Model C, No. 10, lathe shown in Fig. 49. A high-speed precision lathe with fine feeds suitable for fine finish turning with tungsten and diamond tools, it is provided with full electrical equipment. The energized circuits are clearly indicated by lights in the panel mounted above the headstock. The screw-cutting chart and control levers are neatly laid out. This machine, as can be seen in Fig. 49 may be fitted with a universal relieving equipment for producing all types of cutters. Exceptionally long bed covers are worthy of note.

Figs. 50 and 51 show the Maximinor, a single-spindle automatic lathe manufactured by Drummond Bros. Ltd. From the functional point of view, this is a very excellent machine, and it was received with great interest at the last Olympia show.[10] The saddle takes one or two cross-slides: the tailstock can be hand or air-operated. A further point of interest (Fig. 50) is the headstock mandrel speed indicator on the headstock which is available with either high or low speeds. The rear view reveals the former-operated rear slide, the vertical motor-driven coolant pump, the flange-type main driving motor at the rear of the headstock, and below it the electrical gear cabinet. This automatic lathe could be greatly improved from the aesthetic viewpoint by unification of the many broken-up square shapes from the headstock down to the feed box unit including the guard of the quick-traverse motors, and by re-design of the louvres in the guard both as to size and shape. The press button panel and the data and name plates also call for revision. In this process of integration, the contours and radii of the castings require careful scrutiny. The attempts at embellishing the knock-off box, the saddle (Fig. 50) and the change-gear locker (Fig. 51) by decoration with ornamental features unrelated to any practical purpose are to be strongly deprecated.

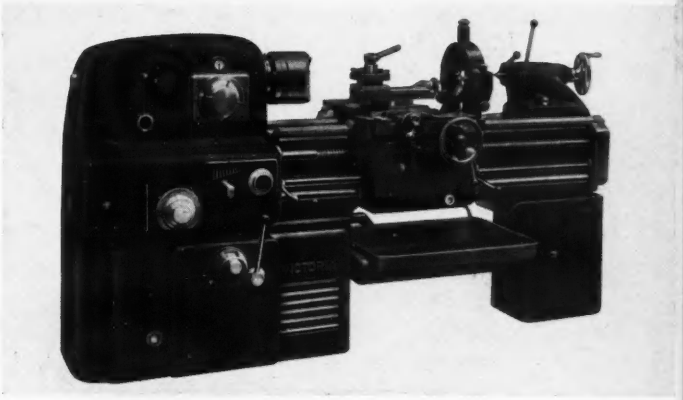


Fig. 47 (above). **Victoria 8-in heavy duty high-speed precision lathe.**

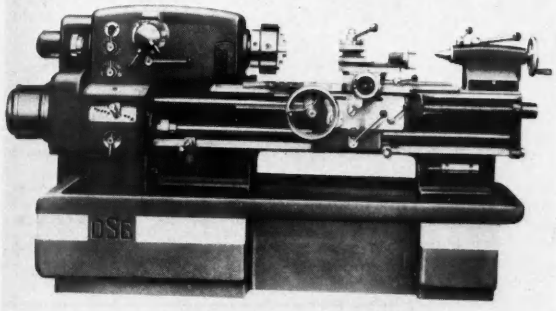
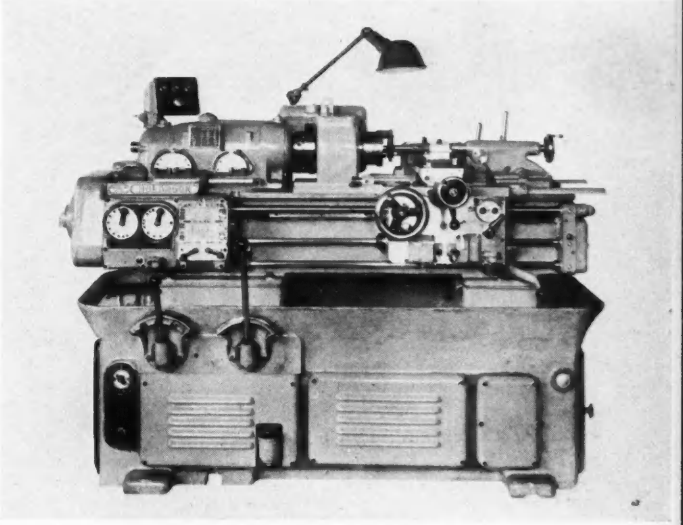


Fig. 48. (left). **Dean, Smith and Grace 13-in swing motor-driven surfacing and boring lathe. (DSG Minor).**

Fig. 49 (below). **Holbrook high-speed precision lathe, Model C, No. 10.**



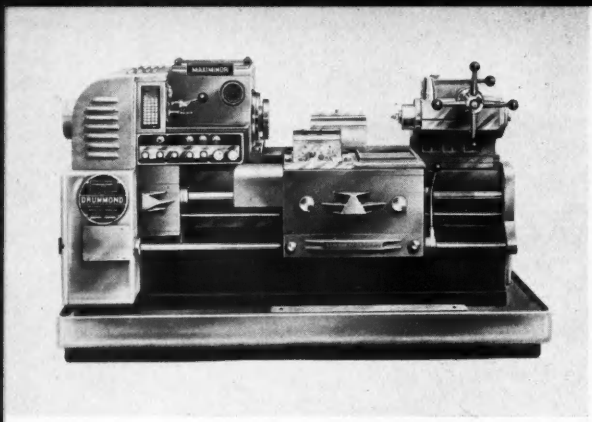


Fig. 50. **The Maximinor automatic lathe.** (Front view.)

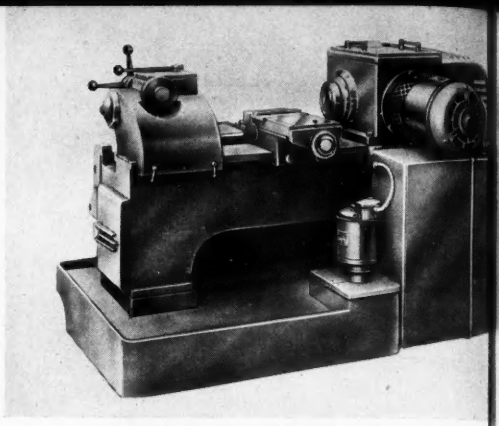


Fig. 51. **The Maximinor automatic lathe.** (Rear view.)

Or is it that functional justification was sought for these ornamental features insofar as they disguise lidgrips and door handles? It is, however, most important to have a sense of proportion and it must be borne in mind that the foregoing criticism refers partly to minor points of appearance. The evaluation of the merits and demerits of a machine tool should be made in terms of mechanical engineering, and points of appearance weighted accordingly. Thus, from the point of view of productive efficiency, i.e., precision of work attainable, ease of operation and maintenance, the Maximinor still scores highly.

A strikingly robust construction is the Swiss Tavannes single-spindle automatic lathe (Fig. 52) which, in contradistinction to the Gisholt and Maximinor, has a travelling headstock. The main mechanism is fitted within the frame, yet so as to be relatively easily accessible. This arrangement results in simple forms of robust compactness and leaves no mechanical part exposed. There is nothing superficial in this machine, which is strictly rational in approach and devoid of any attempt at decoration. Apart from its simplicity, the rugged forms achieved are clean and smooth and the effect obtained is similar to that of modern architecture, where vast areas achieve their effect by contrast and balance rather than by intricate decoration. This machine may be regarded as an example of best contemporary industrial design, in which parts are harmoniously integrated in a purposeful whole.

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(13) Prof. L. D. Hay. Functional Design. *The Engineers' Digest*, June, 1949, pp. 210-211.

(14) The Machine Tool and Engineering Exhibition at Olympia.—*Engineering*, Nos. 4309 and 4310, 1948.

This concludes the "Lathes" section of this article. Milling and grinding machines, as well as special machine tools, will be discussed in future issues.—Ed. E.D.

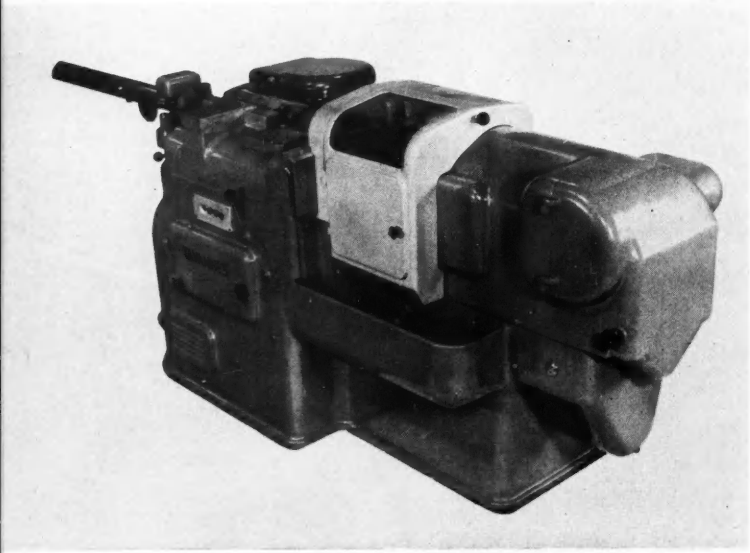

Fig. 52. **Tavannes single-spindle automatic lathe.**

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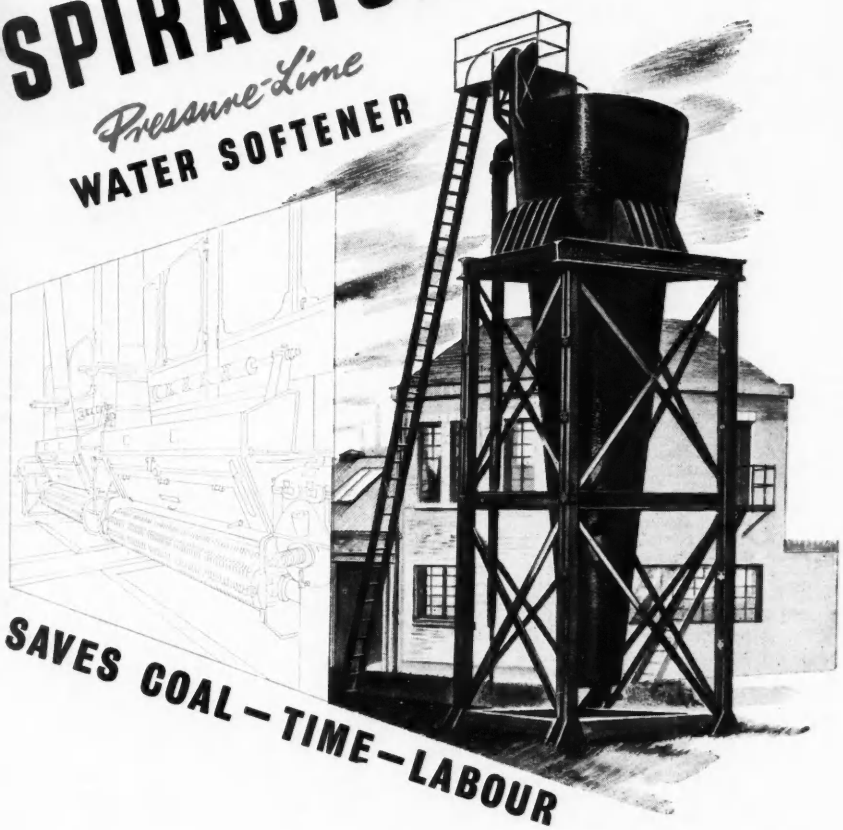

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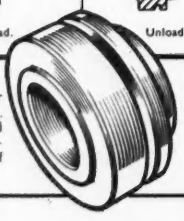
No. 3 STATION — Countersink. Finish turn O.D	No. 3 STATION — Turn O.D. Ream. Form groove.
No. 4 STATION — Core drill bore. Form end.	No. 4 STATION — Turn. Form taper. Ream
No. 5 STATION — Unload and load.	No. 5 STATION — Unload and load.



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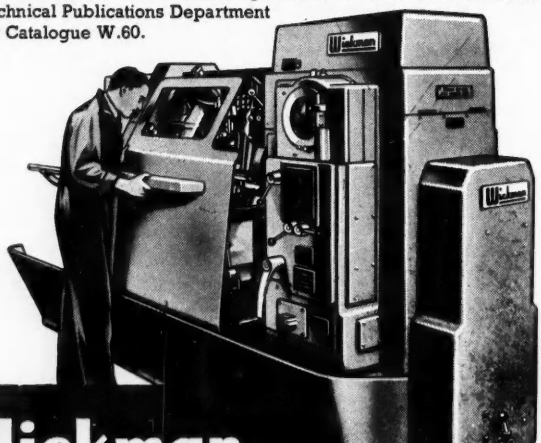

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CLASSIFIED ABSTRACTS

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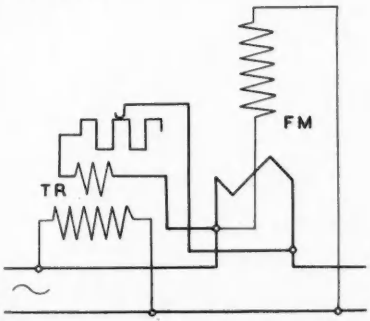
ELECTRIC INSTRUMENTS AND METERS

A new Overconsumption Watt-hour Meter

By G. TEGLAS. (From *Elektrotechnika, Hungary*, Vol. 41, No. 2, February, 1949, pp. 38-39, 2 illustrations).

IT is unusual to fix a low charge for a certain basic demand of an electrical energy consumer. Any consumption above the basic demand is charged at a higher rate and is measured by an overconsumption meter. The overconsumption meter begins to indicate only when the driving torque of the power becomes greater than a counter-torque predetermined in accordance with the basic demand limit. The counter-torque is usually applied by means of a spring or some other mechanical device. The firm of Ganz & Co. Ltd., however, has designed an overconsumption meter which applies the counter-torque by electrical means, thus avoiding the additional friction losses and errors inherent in a mechanical device. This consumption meter is illustrated below. FM is the usual mechanism of a watt-hour meter. The counter-torque is produced by the special transformer TR feeding the current coil of the meter in the opposite direction. The meter, however, is unable to rotate backwards. The counter-torque current is set by a sliding resistance and remains very steady, even when the voltage at the primary of the transformer varies.



There are many uses for overconsumption meters. They possess great advantages over maximum demand meters, as their indications give a fair deal to both producer and consumer. They can also be designed to charge differently according to the time of the day, and in this form they are very useful for the measurement of the reactive volt-ampere-hour demand of the consumer.

ELECTRIC MACHINERY

Vaporisation Cooling of Electric Machines

By T. DE KONING. (From *Electrical Engineering, U.S.A.*, Vol. 60, No. 5, May, 1949, pp. 385-392, 7 illustrations).

THE Effectiveness of the removal of the waste products of a body determines its producing power. In electric machines the coolant and its application are therefore of primary importance. With vaporization cooling the waste product—heat—is removed by the coolant passing from the fluid state into the vapour state.

Vaporization cooling makes a standard universal solution feasible for the cooling of large machines of all types. Water is supplied in mist form to the natura surfaces bordering the air gap. The gap and the space surrounding the end windings are kept under vacuum. Compared with air cooling, the heat transfer coefficient is at least 50 times as great. At full load, 1/80 of the weight and two-fifths to one-fifth of the gaseous volume are needed ; less is needed at part-loads. This gives an indication of the potency of the coolant.

The fundamentals of vaporization cooling prove in short that

1. The heat losses are removed as evenly as they are generated.
2. Air vents, which made up 4 to 12 per cent of the core length, are no longer needed. The resulting solid stator core is explosion-proof and corrosion-proof.
3. The stator core circumference becomes the outside of the machine.
4. Cooling fluid can be applied in accordance with the need. The vapour has a small surface friction. Both are explosion-proof, non-inflammable, and will remove any kind of dust and undesirable substances fully.
5. Fans and gas filters become superfluous. The coolers required for closed circuit cooling become considerably smaller. Auxiliary apparatus hardly is needed. Most of it is simple and fully developed.
6. Compared with hydrogen cooling, vaporization cooling eliminates heavy housing, purifying equipment, and shaft sealing devices.

ELECTROPLATING

Deposition of Metals on Aluminium by Immersion from Solutions Containing Fluorides

By S. HEIMAN. (From *Journal of the Electrochemical Society, U.S.A.*, Vol. 95, No. 5, May, 1949, pp. 205-225, 5 illustrations.)

A NEW process has been developed for depositing zinc, cadmium, and tin by chemical displacement upon aluminium. The immersion solutions contain the metal sulphate and either hydrofluoric acid or the fluoride anion. The deposited metals have a good appearance and sound structure, and their adhesion to the aluminium, which does not depend on any roughening of the aluminium surface, is excellent. The bond between the zinc deposit and aluminium is better than that given by any of the other metals deposited and is greater than the cohesive strength of the aluminium base metal. The zinc immersion deposit may thus be used as a base for plating other metals. The effectiveness of the method results from the extraordinarily high solubility of the oxide film on the aluminium in solutions containing the fluoride anion in acid environment. This is shown from published solubility data and is demonstrated by potential measurements.

FOUNDRY PRACTICE

Precision Casting with Frozen Mercury Patterns

By W. M. NEIMEYER. (From *The Iron Age, U.S.A.*, Vol. 163, No. 11, March 17, 1949, pp. 94-97, 5 illustrations.)

A NEW casting process, which makes use of frozen mercury for the pattern, and a fired ceramic shell-like material for the mould, is now being used by the National Bronze & Aluminum Co., of Cleveland, Ohio, under licence from the Mercast Corporation, of New York. With this process designs involving threaded

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holes, internal contours and other intricate features are now a practical possibility.

A precision die is required. This is made of steel, aluminium, or certain non-metals capable of withstanding amalgamation or attack by mercury. Low-temperature alloys used for the die must be plated after machining. To reduce cost, dies can be constructed of assembled sections.

After assembly, the dies are partly immersed in a cold bath, and a lubricant is poured into the cavity. Liquid mercury is then poured into the die, displacing the lubricant, and freezing takes place gradually, the temperature being lowered to well below –40° F, the freezing point of mercury, by means of dry ice or mechanical refrigeration. No shrinkage allowances are required for solidification of the mercury pattern, but gates and risers require careful designing. In cases where internal cores cannot be withdrawn, frozen mercury patterns are made in sections, and then brought into contact. The sections coalesce instantaneously and are fully bonded by contact.

A film of molecular thickness is thus produced, and towards the end of the freezing process, a rod is inserted into the riser to remove the pattern from the die. The frozen mercury pattern is then dipped a number of times in a ceramic slurry, each coat being allowed to dry before the next dipping, and ceramic is built up to about $\frac{1}{8}$ inch. The mercury is then melted out gradually by spraying it with warm mercury.

The ceramic mould thus obtained is fired for a period of up to one hour, so as to give a shell with a fine inner surface. The mould is thereafter inserted in a flask and backed with dry sand, and after preheating, the molten metal (aluminium, bronze, steel, or high-temperature alloy) is poured in at any temperature up to 3000° F. The ceramic is then removed by light sand-blasting, and the finished casting, weighing from a few ounces to 60 pounds or more, is obtained. The thin shell used and its high permeability give an increased rate of cooling, and successful results with very intricate designs illustrate the advantages of this new technique. The precision castings practically eliminate machining operations, since tolerances of 0·0015 inch per inch are obtainable, and highly-resistant alloys can thus also be cast to any required shape.

LUBRICANTS AND LUBRICATION

Observation of the Lubricating Oil Film between Piston Ring and Cylinder of a Running Engine

By R. L. Brooks and M. L. Atkin. (From *Aeronautical Research Report ACA-42*, Council for Scientific and Industrial Research, *Australia*, September 1948, 13 pages, 21 illustrations).

The effect of various oils and additives on the lubrication between the top piston ring and cylinder wall of a single cylinder aircraft engine has been studied by measuring the electrical contact resistance. The engine was run under its own power at 1,700 rpm and tests were carried out on each oil and additive over a wide range of engine conditions. The effect of viscosity could not be accurately assessed, as it was impossible to maintain a constant oil supply to the cylinder wall with oils of different viscosities, and any deterioration of the trace with the lighter oils was offset by the increased supply of lubricant. It is shown that the addition of oiliness agents to straight mineral oils has no effect on the resistance trace. The only additives to show an effect were of the anti-wear type such as tri-cresyl-phosphate, and oiliness agents used in conjunction with them. With additions up to $1\frac{1}{2}$ per cent of an anti-wear additive a gradual increase in the electrical contact resistance was observed. Further improvement was obtained with the subsequent addition of a suitable oiliness agent. The improvement in the lubrication trace due to these additives is in agreement with their observed ability to reduce wear. The results indicate that physical rather than chemical factors determine the breakdown of the oil film. Nevertheless the chemical nature of the lubricant can materially affect the existing physical conditions.

OPEN HEARTH FURNACE PRACTICE

The Influence of Manganese upon the Metallurgical Reactions in the Basic Open Hearth Process

By S. Fornander. (From *Jernkontorets Annaler, Sweden*, Vol. 133, No. 5, May, 1949, pp. 163-190, 21 illustrations)

In order to ascertain the effect of the manganese content of the charge upon the reactions occurring in the basic open-hearth furnace, thirty-six experimental heats were made at four different steelworks. A new method was developed for taking steel bath samples suitable for oxygen content determinations. The method gives reproducible results.

The manganese content of the charge, which was varied between 0·15 and 2·3 per cent, has no influence either upon the oxygen content of the bath or upon the rate of carbon drop. The carbon content of the bath is the factor which has the greatest influence upon the oxygen content during the refining period. The values of the product [C] × [O] are rather scattered at higher carbon contents, but approach the equilibrium value at lower carbon contents. The oxygen content of the steel increases linearly with time towards the end of the heat. There seems to be a linear relationship between the rate of oxygen increase and the rate of carbon drop at lower carbon contents.

The MgO content of the slag is decreased if the manganese content of the charge is increased.

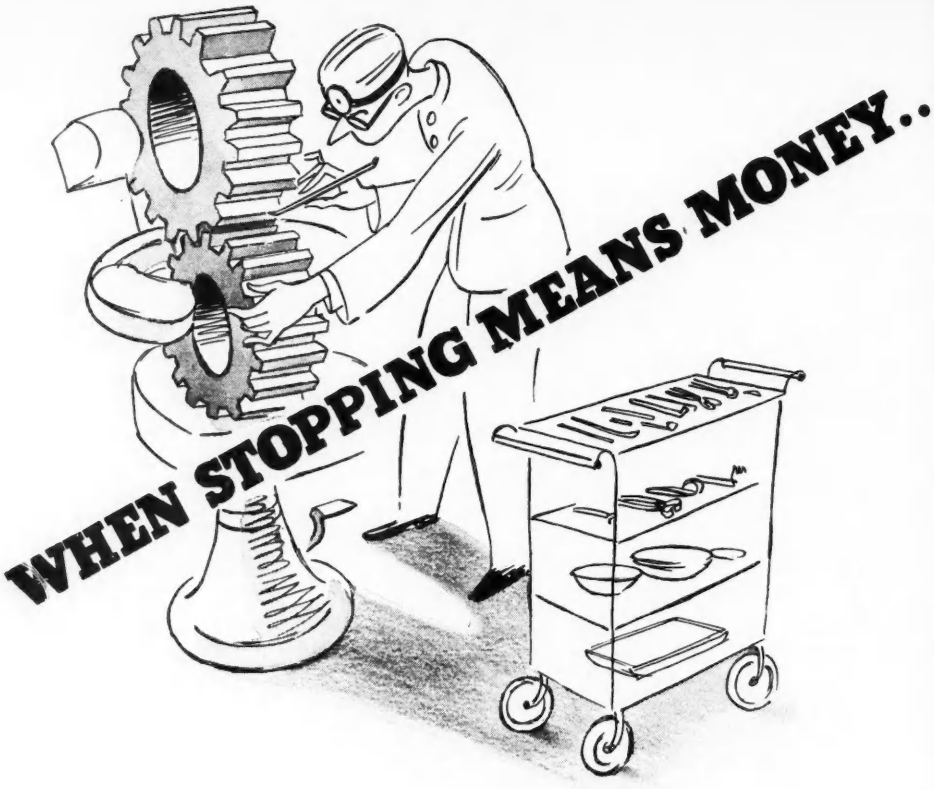
The results obtained give no answer to the question as to whether a high manganese content of the charge would be beneficial to the process. Further investigations should be concentrated upon the role played by the slag during refining, and especially upon its capability of transferring heat to the bath.

STRESS ANALYSIS

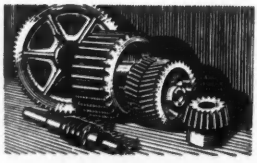
Relation of Experiments to Mathematical Theories of Plasticity

By D. C. Drucker. (From Paper No. 49-APM 5, presented at the National Conference of the Applied Mechanics Division of *The American Society of Mechanical Engineers*, June 13-15, 1949, 9 pages, 11 illustrations.)

Several classes of mathematical theories of plasticity for work-hardening materials are surveyed and their advantages, and agreement with experiment discussed. Consideration is given to the proper correlation of tests on thin-walled tubes subject to tension, torsion, and the internal pressure in fixed, but arbitrary, ratio. The continuing debate between octahedral-shearing-stress and maximum-shearing stress criteria of plastic deformation is re-examined and the more general alternatives are re-stated. Through an analysis of Osgood's experimental results, it is made apparent that the more general point of view is required for the best correlation. A series of experiments is outlined which makes the distinction between the various criteria of loading or deformation very large, instead of just a few per cent, as in previous work. In the evaluation of present mathematical theories it is shown that incremental-strain theories avoid obvious drawbacks of the so-called deformation type of theory. The concept of isotropic work-hardening assumed in pactically all



it is usually the teeth which have worn, and the only really satisfactory way to deal with the problem is to have a new 'set'. This is our job in life, to provide gear wheels which will 'fit' and do a lasting job of work, or provide a complete new 'set' of gears.



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Stress Analysis—*Continued.*

stress-strain relations is explored and generalized. Strong limitations indicated by the Bauschinger effect, which cannot appear properly in such theories, are pointed out.

VIBRATIONS

Holzer Method for Forced-Damped Torsional Vibrations

By T. W. SPAETGENS. (From Paper No. 49-APM-12 presented to *The American Society of Mechanical Engineers* on June 13, 1949, 5 pages, 4 illustrations, 6 tables).

THE forced and resonant-vibration characteristics of a torsional system are easily enough determined by the well-known Holzer methods, in the case where the only major damping influences available in the system are those of the prime-mover itself, or of the propeller, in the case of a propeller-propulsion system. Where a damper exists within the system, the classic solution confines itself to the determination of the *resonant*-vibration characteristics under optimum damping conditions, and utilizes the principle of energy balance in conjunction with an equivalent system. The problem of *forced* vibration in a system having a damper is not susceptible, however, to such simple treatment regardless of whether or not the damping is optimum. This paper outlines an exact method, whereby both the forced- and the resonant-vibration characteristics of a viscously damped system may be calculated for any existing damping condition, optimum or otherwise, and which utilizes the ever-popular Holzer form.

Vibration Control of Engines

By L. E. MULLER. (From *Product Engineering, U.S.A.*, Vol. 20, No. 4, April, 1949, pp. 86-89, 11 illustrations.

A MECHANICAL STROKER for tests of the behaviour and dynamic properties of rubber materials used in anti-vibration mountings has been developed by the Buick Motor Division of the General Motors Corporation. A schematic diagram of the machine is shown in Fig. 1.

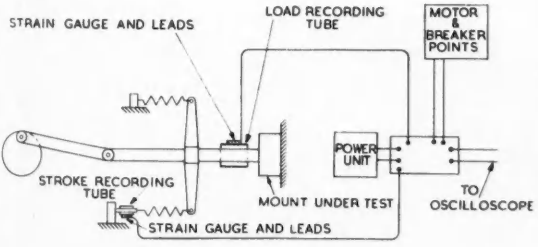


Fig. 1. **Mechanical stroker for studying motor mount materials.**

The mount under test is fixed on a bracket which is bolted to a base plate. A compressive or tensile pre-loading is obtainable by adjusting the position of the base-plate. The dynamic load is applied by a reciprocating arm by means of a crank, which is driven by an electric motor.

The load is measured by strain gauges on a load-recording tube, and the corresponding displacement by strain-gauges on a stroke-recording tube. The strain-gauge outputs are then monitored on a cathode-ray oscillograph, in the form of hysteresis loops, such as those shown in Fig. 2. The area of these loops can be determined by suitable calibration, and gives the energy in inch-pounds dissipated during each hysteresis cycle.

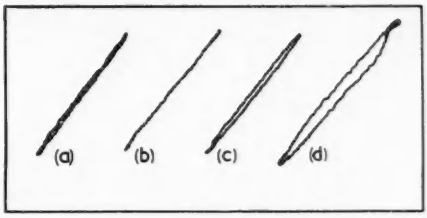


Fig. 2. **Vertical shear hysteresis loops as photographed from a cathode-ray screen.** They show comparative damping qualities of (*a*) natural rubber, (*b*) neoprene, (*c*) neoprene of higher hysteresis and (*d*) GR-S rubber. The areas represent energy dissipated.

WIRE AND WIRE PRODUCTS

An Apparatus for Detecting Surface Cracks in Wires

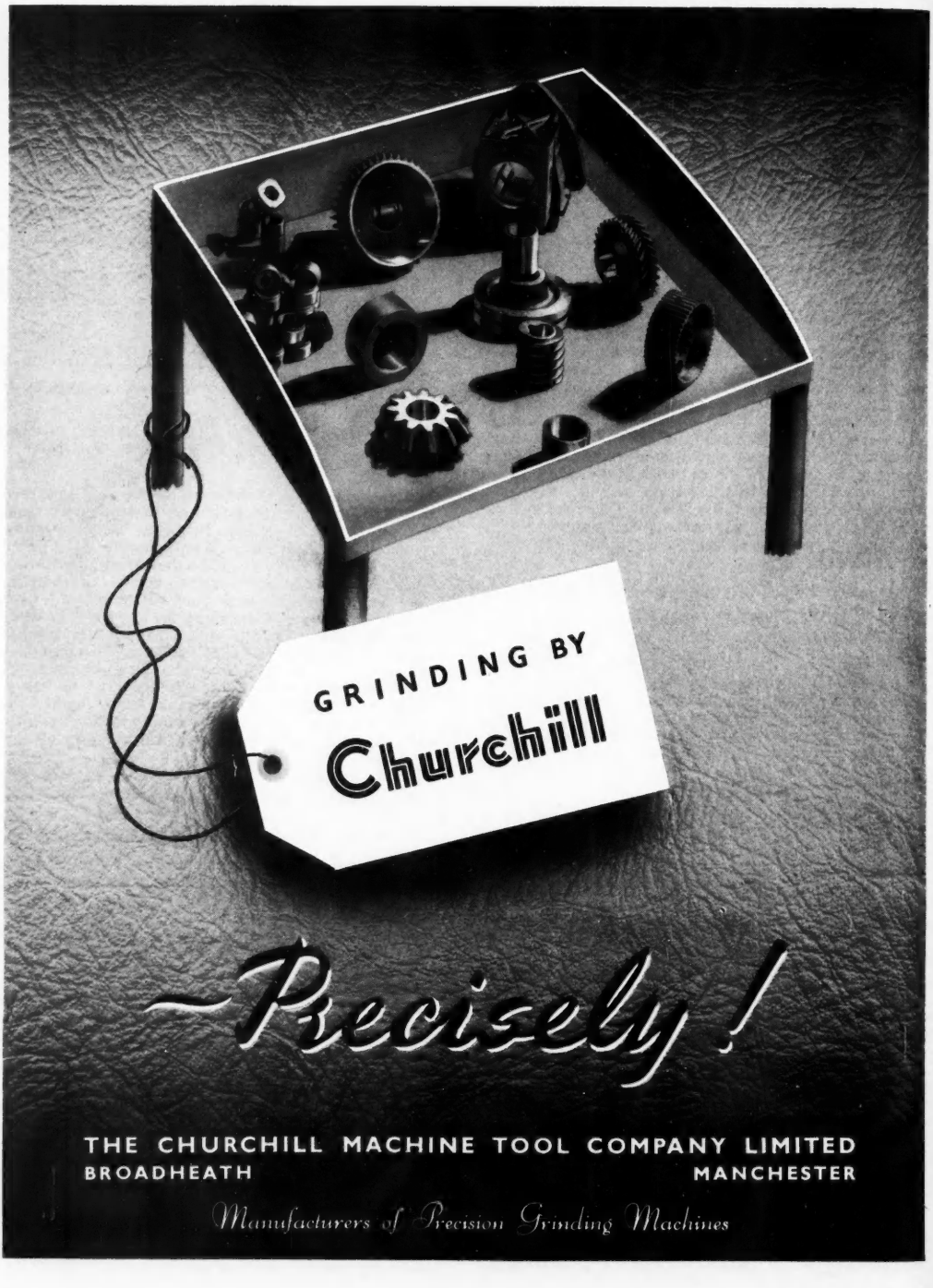
By P. ZIJLSTRA. (From *Philips Technical Review, Holland*, Vol. 11, No. 1, July, 1949, pp. 12-15, 5 illustrations).

FOR the proper functioning of electronic valves there should be no fine cracks at the surface of the leads passing through the glass. In this article an apparatus for the detection of such cracks is described. The rod or wire under test is placed in a measuring coil, through which a high-frequency current is passed. If there is a crack in the wire, the impedance of the coil will differ from that obtained with a sound rod or wire. To determine this difference, the coil is included in the grid circuit of an oscillator. The extent of the variation in impedance is derived from its influence upon the control-grid current. The method is sufficiently accurate to detect cracks of about 0·1 mm depth. The use of this apparatus is not confined to the testing of valve leads ; it can also be used in other cases for wire testing.

EDITORIAL—*Continued from page* 305.

Chairman of the Advisory Council on Scientific Policy and the Defence Research Policy Committee, was even more emphatic. " Unless we can hasten the application of science to industry," he said, " we shall cease to count among the great nations of the world. We can only escape disaster if we make things better and cheaper and if we are bold and adventurous in industry. There must be changes, and changes on a big scale, if we are to recover our balance, let alone maintain our standard of living. The alternative is for men to work much harder for longer hours at much lower wages ; and none of us wants that except in the last resort."

To promote the application of science to industry has been the aim of this journal since its inception. We know of many instances in which new machines, new devices, new products and new processes have been developed by industry, inspired by articles published in " The Engineers' Digest." Whilst a large majority of progressive engineering firms have made use of our services for many years past, it is hoped that these services can now be made available to all who have been deprived of them either through lack of appreciation of their vital importance or because of the severe paper rationing, which as yet has only been slightly relaxed.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NEWS OF THE MONTH

PERSONAL.

Mr. A. A. Pollock, B.Sc., Director and Chief Mechanical Engineer of The British Thomson-Houston Company has retired, but will be available in a consultative capacity.

Mr. K. R. Hopkirk, M.A., has been appointed to succeed Mr. Pollock as Chief Mechanical Engineer.

BUSINESS NOTES

Protolite Ltd., Central House, Upper Woburn Place, London, W.C.1. announce the opening of additional offices in the following industrial centres :—Birmingham, Guildhall Buildings, Navigation Street ; Manchester, Northern Assurance Buildings, Albert Square ; Leeds, Norwich Union Buildings, City Square ; Newcastle-on-Tyne, Norwich Union Chambers, 42 Westgate Road ; Glasgow, 144 St. Vincent Street.

LICENCES FOR COLD PRESSURE WELDING.

World wide interest has been created in the Cold Pressure Welding process developed by the General Electric Co. Ltd. in its research laboratories.

The Company has now decided that since this method of welding can be put to a wide range of uses, both inside and outside the electrical field, industry as a whole should have access to the process, so that the technique can be exploited and developed in the widest possible way.

Arrangements have accordingly been made for the issue of non-exclusive user licences to all firms who wish to use the process (except for certain electrical uses) at a low royalty rate to be settled separately for each firm.

The G.E.C. will not undertake any specialised development work on projects put forward from outside the Company, but advice and demonstrations will be given at its Research Laboratories to enable potential users to gauge whether the process is suitable for their particular requirements. An arrangement has also been made with a London firm whereby specialised tools and machines can be manufactured and supplied to users of the process.

A copy of the G.E.C. brochure on Cold Welding will be forwarded on application to Magnet House, Kingsway, London, and quoting the reference PUBL/JHJ.

NEW COAL-BURNING LOCOMOTIVE

A NEW type of coal-burning, electric locomotive that will use only half as much fuel as the conventional steam engine and yet pull a freight train 65 mph soon will be built in the U.S. for the Norfolk and Western Railway. The locomotive will be constructed by the Baldwin Locomotive Works in collaboration with the Westinghouse Electric Corp. and Babcock and Wilcox. The new 4,500 hp locomotive for the first time will put a coal-burner on an equal footing with diesel electrics as far as fuel costs and operating efficiency are concerned.

Norfolk and Western and the three manufacturers will share in the development and production cost of the new locomotive which is estimated at more than a million dollars.

Key to the engine's remarkable efficiency will be a radically new high pressure, water-tube boiler built by Babcock and Wilcox. Coal-fired, it will produce steam pressure of 600 psi, about double that of the ordinary steam locomotive boiler. Because of this high pressure, less steam—thus less fuel—will be needed to operate the steam turbine that runs the locomotive's electric generator. This direct current generator, in turn, will operate the 12 electric driving motors that are to be mounted one on each axle of the locomotive.

The steam turbine and all electrical equipment will be built by Westinghouse. Baldwin will design and build the running gear, cab, tender, and other mechanical parts of the locomotive and will be responsible for its final erection. The unit will appear to have been "built backwards" to the casual observer. Twenty tons of coal will be carried in the nose of the engine ahead of the operator's cab. A tender carrying 16,000 gallons of water will be behind the locomotive. Overall length, including tender will be 148 feet and weight will be 952,000 pounds.

An important factor in the design of the new locomotive is the advantage of using coal. The new high-pressure boiler development makes it possible for coal to compete on a comparable cost basis.

NEW IMPROVEMENTS ON DUAL FUEL DIESEL ENGINES

GREATER efficiency and smoother operation over a wide load range are claimed for the new Dual Plunger Fuel Pump and Automatic Thermal Air Control, now standard equipment on Dual Fuel Diesels built by Worthington Pump and Machinery Corporation.

The Dual Plunger Fuel Pump incorporates in one unit the requirements for a pump to handle the full load of the engine on oil operation, and at the same time provides the most effective method of handling the small quantity of pilot oil for burning the gas fuel.

A small diameter pilot plunger, mounted in tandem with the main plunger, produces perfect atomization with short, localized penetration into the combustion chamber, resulting in lower firing pressures. Lower exhaust temperatures and improved fuel consumption are direct indications of more efficient combustion.

For the first time, Automatic Thermal Air Control is adapted to Dual Fuel Diesels. This provides the correct air fuel ratio at all times and in direct relation to all load changes. The most responsive medium—engine exhaust temperature—is utilized to actuate this control. Daily and seasonal ambient air temperatures can be compensated for by simple, quick, adjustment of the controller setting.

Nylon in Combination with Cotton is fast becoming the favoured material for the construction of heavy duty conveyor belts used in copper, iron ore and coal mines and other installations where belts must withstand severe service.

The versatile plastic is used as a cross-wise fibre in conveyor belt fabric, and cotton yarn is the best textile for the longitudinal fibre in belt construction found to date.

Use of nylon in combination with cotton yarns makes possible a greater number of fabric plies which increases the overall belt strength by as much as 250 per cent. At the same time, nylon gives a thick belt far greater flexibility, a characteristic essential for efficient operation.

The greater strength of nylon-cotton construction means a tougher belt which will resist tearing and cutting due to accidents, thereby reducing cost of maintenance and repairs.

A National Industrial Cost-Cutting Exposition sponsored by the American Society of Tool Engineers has been scheduled for April 10th to 14th, 1950, in Philadelphia, Pa.

Although the Tool Engineers' Industrial Expositions have become a regular biennial institution, the 1950 Show takes on added importance due to the recognized necessity of reducing manufacturing costs to bring prices down. The 1950 show will concentrate, therefore, on equipment, processes, etc., designed to reduce manufacturing costs.

Notification of interest in visiting the exposition should be addressed to the American Society of Tool Engineers, 10700 Puritan Avenue, Detroit 21, Michigan, U.S.A.

Specialist Team on Mechanical Aids. A team sponsored by the Anglo-American Council on Productivity will be leaving shortly for the United States to study mechanical aids and handling devices for use in the factory and the use of power-operated hand tools. These will be looked at primarily from the aspect of the user though the manufacturers of such appliances will also be visited.

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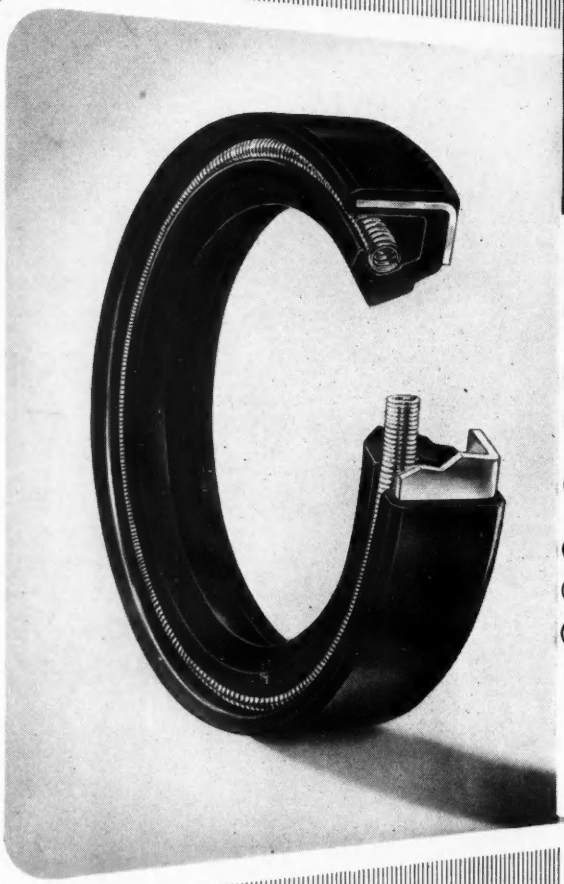

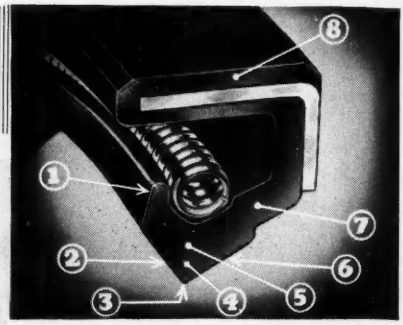

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BOOKS

Fluid Pressure Mechanism. By H. G. Conway. Publishers: Sir Isaac Pitman & Sons Ltd., Parker Street, Kingsway, London, W.C.2. 218 pp. 175 illustrations. PRICE 25/-.

Approximately 500 devices are described and illustrated in this book which deals with the mechanism of fluid pressure equipment and systems. Hydraulic, pneumatic and compressed gas systems of high, medium and sometimes low pressure, are covered, and the author attempted to classify the various devices on a logical basis and to standardize nomenclature and the methods used in the drawings.

The illustrations are excellent, the material is well arranged. The book satisfies long-felt demand.

Reference Book on Electrical Engineering (Kleines Hilfsbuch fur die Starkstromtechnik). By Prof. Dipl. Ing. R. HUBAUER, with the collaboration of Dr. Ing. PETZOLD, Dr. Ing. RITTER, Dipl. Ing. BUSCHMANN and Dipl. Ing. CHARVAT. Publishers: Franz Deuticke Verlag, Vienna. 219 pp., 201 figures. PRICE: Swiss francs 10.50.

This book contains an extensive amount of theoretical and practical data and should be extremely useful to electrical engineers. The first three sections are devoted to mathematics, and to the properties and strength of materials. These are followed by sections on electro-chemistry, the fundamental electrical formulae, electrical illumination, and measuring instruments. The last and most comprehensive section deals with electrical machines (transformers, switchgear, asynchronous and synchronous machines, d.c. machines, and d.c. and a.c. commutator motors). The formulae given in each section enable approximate and detailed calculations to be made of the electrical and mechanical characteristics of the electrical equipment under consideration. Graphical methods are also used wherever necessary.

Hot Tinning. By W. E. HOARE, B.Sc. (Eng.), F.I.M., A.I.P.E. (112 pp. with 47 illustrations). Published by Tin Research Institute.

This booklet provides complete working instructions for the production of hot-tinned coatings on fabricated articles and components.

It is essentially a practical manual, compiled primarily to meet the needs of operative tinners, foremen and design engineers. Where theoretical discussion is deemed to assist understanding of technique, such discussion is given as simply as possible. Considerable attention is devoted to plant requirements and useful hints on plant lay-out are provided.

The procedures used for cleaning, pickling and fluxing ferrous and non-ferrous metals in preparation for the actual hot-dipping operation are fully dealt with. The composition and characteristics of the various cleaning, pickling and fluxing solutions, and instructions for their preparation and maintenance are given.

The dip-tinning operation in its various forms is described in extensive detail. The sections dealing with the actual dipping processes describe techniques for the coating of steel, cast-iron, copper and other metals in both pure tin and in tin-lead alloys and special attention is given to certain new techniques, developed at the Tin Research Institute laboratories, for the tinning of steel and cast-iron. The booklet concludes with a chapter on the examination and testing of hot-dip tinned coatings.

The booklet contains an adequate bibliography and is illustrated by numerous diagrams, flow sheets and plant photographs. It is obtainable, free of charge, on application to :—

Tin Research Institute, Fraser Road, Greenford, Middlesex.

Tin Research Institute, Inc., 492, West Sixth Avenue, Columbus, 1, Ohio, U.S.A.

Centre d'Information de l'Etain, 31, Rue du Marais, Brussels, Belgium.

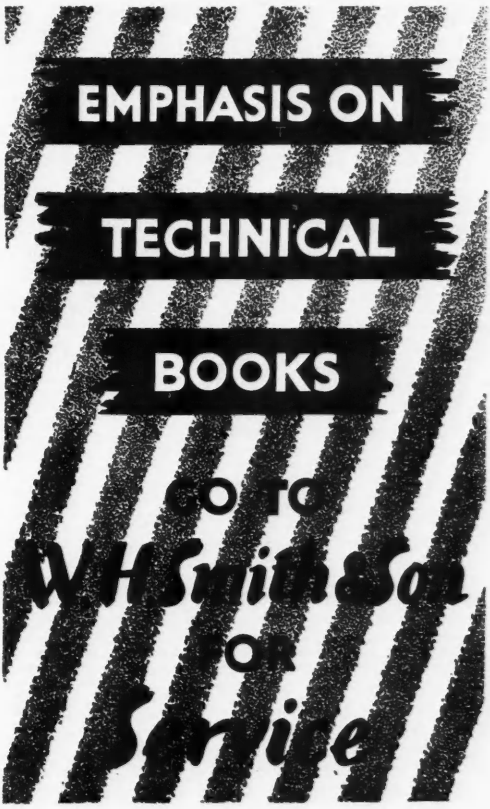
N. V. Billiton Maatschappij (Commerciele Dienst), Louis Coup erusplein 19, The Hague, Holland.

Tool Engineers Handbook. A reference book on all phases of planning, control, design, tooling and operations in the mechanical manufacturing industries. Edited for the American Society of Tool Engineers by Frank W. Wilson. Publishers: McGraw-Hill Book Company, 330 West 42nd Street, New York 18, N.Y. 2070 pages. PRICE $15.00.

This comprehensive and authoritative book on the subject of mechanical processing of finished products covers all new important techniques and processes. The contents can be classified under the following major headings :—Planning and Control of Production; Inspection and Quality; Materials and Machinability; Casting and Extruding Operations; Metal Cutting; Grinding; Finishing; Metal Forming; Welding, Gluing and Mechanical Joining of Materials; Surface Finish and Protective Coatings; Peening; Balancing; Gaging; Inspection; Testing; Fixture, Die and Tool Design; Limited-Production and Master Tooling; Machine Tool Controls and Feeding Devices; Design of Threads; Gears; Bearings; Springs; Other Elements; Mathematics; Physics; Reference Tables.

Nickel Properties and Applications. A further publication in the series dealing with the properties and applications of their alloys is published by Henry Wiggin & Co., Ltd. It includes data on mechanical properties of nickel, its corrosion-resistant qualities in addition to a number of applications with typical illustrations of equipment in various fields.

Copies of this publication, together with those on Inconel and Monel & K. Monel, are available on application to Henry Wiggin & Co. Ltd., Wiggin Street, Birmingham 16.



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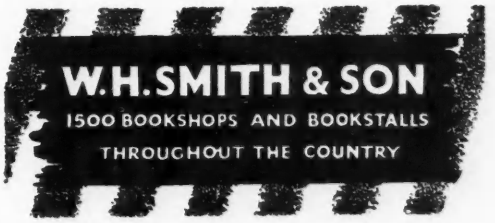

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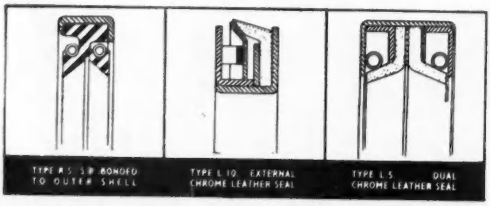

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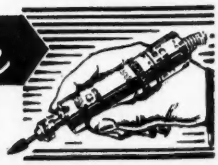

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A COLD 458 BELOW REACHED AT WESTINGHOUSE CRYOGENICS LAB.

ARMED with a completely new laboratory Westinghouse scientists are probing deeper into the mystery of how matter behaves at temperatures a fraction above the world's coldest cold—absolute zero.

Dr. Aaron Wexler, head of low-temperature studies at the Westinghouse Research Laboratories, Pittsburgh, Pa., disclosed that a new cryogenics laboratory is producing custom-made temperatures all the way down to 458 degrees below zero Fahrenheit. Using special techniques, the scientist can come within one-tenth of a degree of absolute zero—459.7 degrees below zero on the Fahrenheit scale.

"At such temperatures," Dr. Wexler explained, "the nature of matter undergoes radical changes and behaves in a most mysterious manner. For example, liquid helium flows uphill and the flow of electricity in a wire encounters no resistance at all. Although these facts have been known for years, scientists are striving to find out why this should happen.

"Our quest is aimed at uncovering fundamental explanations of this mysterious behaviour at sub-zero temperatures."

One major mystery now under attack, the scientist said, was the resistance-free course that extremely low temperatures provide for electricity.

"Normally, electricity flowing through a wire will meet resistance and lose some of its power in the form of heat. But if you immerse the circuit in liquid helium—with a temperature of about 452 degrees below zero Fahrenheit—it will continue to carry current even though the source of electricity is shut off.

"This strange behaviour, which scientists call 'super-conductivity,'" Dr. Wexler added, "may be of great significance to future power transmission. If it could be properly harnessed, it might mean much more efficient and cheaper distribution of electricity. A thorough understanding of the nature of resistance-free conductivity may be the key to unlock this door."

Only certain metals—thirteen of them thus far—are superconducting at sub-zero temperatures, he said. Among the most important of these are columbium, tantalum, vanadium, and their alloys, because they become resistance-free at temperatures that are relatively "high."

"Pure columbium will conduct electricity without resistance at a temperature of 16 degrees above absolute zero, while its nitride will perform the same feat at 29 degrees above. A major aim of our research is to find metals or alloys that are super-conducting at higher and higher temperatures—thus reducing the problem of refrigeration."

Dr. Wexler's laboratory takes helium gas in at one end and in a series of steps produces liquid helium at the other—with a temperature of 452 degrees below zero Fahrenheit—about eight degrees above absolute zero. Additional methods bring this down to a mere fraction of a degree above absolute zero.

All through the process, electronic and mechanical controls take over. This enables the scientist to keep a constant check on the sub-zero temperature production. The helium gas is stored in tanks that line the ceiling of the laboratory, while the liquid helium is returned to its gaseous form after use and re-circulated into the storage tanks.

The scientist ranked low-temperature research on a par with nuclear physics as a factor in unearthing new information on the ultimate structure of matter.

Unified Screw Thread Standards. An accord for unification of American, British, and Canadian standard systems of screw threads was signed at the National Bureau of Standards on November 18, 1948. The proceedings of this meeting, together with detailed illustrations, tables, and numerical data setting forth standards of thread form are presented in a new booklet, *Unified Screw Thread Standards*, recently published by the Bureau and now available from the U.S. Government Printing Office, Washington 25, D.C., U.S.A. PRICE 30 cents.

BRITISH STANDARDS

(*Copies of British Standards may be obtained from the British Standards Institution, 24, Victoria Street, London, S.W.*1)

Light-weight Miniature Lubricating Nipples. (B.S. 1486 : 1949 Pt. 3). This standard deals with the aluminium alloy lubricating nipple which is suitable for use where a small, light-weight nipple is required. It is identical with that used on aircraft (AGS 554). It does not deal with the internal construction of the nipple.

The standard provides for overall dimensions and thread sizes, workmanship and finish, permissible variations in dimensions and materials. It also gives the minimum distance at which the nipples can be mounted to permit application of the appropriate lubricating connector.

Parts One and Two are published separately and deal with Lubricating nipples and adaptors for machinery and vehicles and Heavy duty lubricating nipples respectively. PRICE 2/-.

Erratum. In the article on "Plastics in Shipbuilding" on page 282 *ante*, the last sentence in the fourth paragraph, second column should be read :—"The Holoplast" 1-in panel is manufactured with solid linings in thicknesses ranging from 1/32-in to 4-in and in the following variety."

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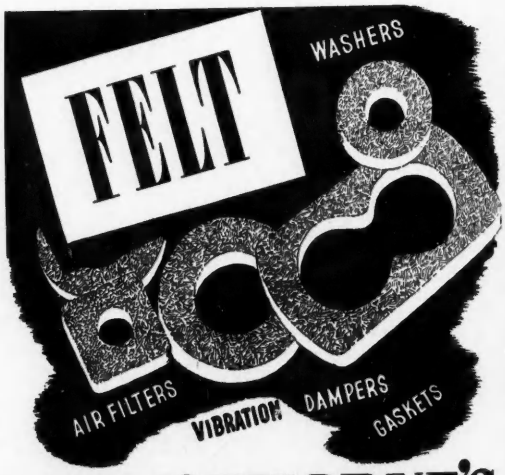

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